BAHMAN CHECK DAMS

Design Report

Sana'a Basin Water Management Project

Project Coordination Unit

Sana'a, Republic of Yemen

Final Report

July 2006

Stanley Consultants INC.

A Stanley Group Company

Engineering, Environmental and Construction Services - Worldwide

in association with

Consolidated Consultants Engineering & Environment

Hani Al Sahooly & Associates Architects and Engineering consultants

CES Consulting Engineering Services, India

SANA'A BASIN WATER MANAGEMENT PROJECT

BAHMAN CHECK DAMS FINAL REPORT

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In association with

AEC **Hani Al Sahooly & Associates, Yemen**
Architects and Engineering Consultants
CES **Consulting Engineering Services, India**
CC **Consolidated Consultants Engineering and Environment, Jordan**

SECTION ONE: INTRODUCTION

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SECTION ONE: INTRODUCTION

1.1 Introduction

The Sana'a Basin is located in the central highland of Yemen, and it includes the capital city of Sana'a. The basin has an area of 3200 km^2 and an average elevation of 2200 m above sea level. Current population of the basin is about 1.5 million, and approximately 300,000 persons live in the rural area. The basin includes 110,000 hectares (ha) of arable land of which 24,000 ha is currently being irrigated. Farms are irrigated through extraction of groundwater through wells. The basin is experiencing a serious depletion of ground water resource with an associated alarming degradation in water quality, due to the rapid growth in population. The situation is further aggravated by the absence of an integrated water resource management plan for the basin including a regulatory framework to manage the ground water extractions; lack of data; and inefficient irrigation practice. Unless immediate remedial measures are taken to improve the basin's aquifers, current levels of water table depletion will create a major crisis in water availability, quality, and supply in the near future. The Government of Yemen is well aware of this fact and is taking steps through the Sana'a Basin Water Management Project

In order to overcome the pressures upon the water supply within the Sana'a Basin, the Government of Yemen and the World Bank prepared the Sana'a Basin Water Management Project (SBWMP). The objective of this program is to seek solutions for sustainable water management and implementation of the same in the Sana'a basin. The immediate goals of the program are: 1) to increase both quantity and quality of the ground water resources available for domestic and industrial use in the basin, and 2) to simultaneously increase the efficiency of agricultural water use so as to develop a less water-intensive, more productive agricultural economy in the rural areas of the Basin.

Artificial recharge enhancement has proven an effective technique in replenishing groundwater resources for areas with suitable topographical and hydrogeological conditions. The basic concept of artificial recharge enhancement is to improve levels of groundwater storage in shallow aquifers as a more economically attractive alternative to exploitation of the deep aquifers for irrigation purposes. Based on previous studies carried out by numerous consultants SBWMP has decided to adopt the concept of artificially recharging the shallow aquifers by constructing dams across the wadis in the Sana'a basin.

1.2 Background

The SBWMP issued a Request for Proposals (RFP) in May 2004, for the topographic survey, preparation of detailed designs, tender documents and construction supervision of the Sana'a Basin Water Management Project. The original scope of work included fifteen dam sites, which were subsequently divided into two Groups, Group A and Group B. Stanley Consultants, Inc. USA; and its associated firms Consulting Engineering Services (India) Private Limited; Architects and Engineering Consultants Hani Al-Sahooly and Associates (Yemen); and Consolidated Consultant Engineering & Environment (Jordan) were selected to complete the designs on dams in Group A. A separate consultant was retained by the PCU for completion of project activities for Group B dams.

Stanley Consultants was invited in March 2005 to begin negotiations on the Group A contract. Negotiations were held in March and April 2005. At that time, some details in the scope of work were changed; in particular, construction services were deleted. The final contract was signed on 13 September, 2005. The date for the commencement of services was set as October 28, 2005. The period of the contract work was set as 24 (twenty four) working weeks.

1.3 Project Objectives

The project objectives remain the same as defined at the beginning of the work program. The primary project objective is as follows:

Preparation of the detailed designs and tender documents of the works for the construction of three new dams and the possible rehabilitation of three existing dams:

New Dams	Existing Dams requiring Rehabilitation
Beryan	Al Lujima
Al Malah	Al Jaef
Al Sinn	Bahman Check Dams

This report summarizes the detailed investigation and design works carried out for Bahman Check Dams.

1.4 Report Objectives

The Final Report (FR) explains the work that has been completed for the Bahman Check Dam project as part of the design of the Group A Dam program. The report contains information on the data collected and analyses performed for completion of the design of the Bahman Check Dam site. It describes the activities and achievements reached in meeting the objectives as set out in the Scope of Work. The FR includes a full, multi-discipline design report, tender documents, specifications, final drawings, bills of quantities, cost estimate and an implementation plan.

The report also includes a separate Chapter addressing the environmental issues outlined in Section 4.6 of the Terms of Reference (TOR). This chapter can be found in the Section Ten: Environmental Issues. The Final Report is required to cross-reference an Environmental Impact Assessment TOR that will be executed by a separate consultant. This TOR was unavailable during the design period. The Project Coordination Unit (PCU) and Technical Advisory consultant, Arcadis Euroconsult, will need to coordinate closely with the EIA consultant. Section Ten contains discussion and recommendations for the activities to be performed by the EIA consultant.

1.5 Deliverables

The deliverables for the Bahman Check Dams Final Report are as follows:

Tender Documents in the following configuration

1. Volume I. Bidding Documents
   Bill of Quantities (unpriced)
2. Volume II. Specifications
3. Volume III. Drawings

4. Design Report (this volume)
   a. Separate Monitoring Plan

5. Separate Confidential Cost Estimate

SECTION TWO: SCOPE OF WORKS

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SECTION TWO: SCOPE OF WORKS

2.1 Scope of Works

The following activities represent the most significant aspects of the scope of work for the Detailed Design and Tender Document Preparation for Three Existing Dams and Three New Dams. Most of these activities remain the same as originally outlined at the beginning of the project.

A. Review of Feasibility Studies completed on each of six dam sites.
B. Evaluation of previously gathered data, identification of data gaps, and collection of missing data.
C. Evaluation of previously completed geotechnical works. Develop and supervise additional geotechnical testing program as required.
D. Review of previously completed topography works, and update topography for final design activities.
E. Evaluation of hydrology for each site, to include validation of SCS-RRM model use; evaluation of catchment area, annual runoff, and storage capacity; calculation of maximum probable design floods; and review of flood frequencies and volumes.
F. Evaluation of hydrogeologic work in the feasibility studies, and identification of any problems or limiting factors.
G. Preparation of questionnaires, stakeholder awareness meetings, evaluation of communities near the dams, and building public awareness for the project.
H. Baseline environmental review of each site and coordination with EIA consultant.
I. Preparation of reports documenting the design and study activities.
J. Training workshops and presentations to the client.
K. Prepare final design drawings for each site, with backup calculations.
L. Prepare Bill of Quantities for each site.
M. Prepare Specifications for each site.
N. Complete Tender Documents for the project.

2.2 Activities Removed from Scope of Work

The following items were removed by the Client from the original scope of works to be performed under this contract. Input from the subject experts was also reduced accordingly.

a. Hydrogeology scope of services will be limited to the six dams included in the Contract, and did not include the following:
    - Conceptualizing, calibrating and running numerical groundwater models.
    - Developing and delivering technical presentations to the client.
b. The Local Water Quality scope of services was limited to the six dams in Group A, and it did not include developing and delivering technical presentations to the client.

c. Construction Supervision was removed from the Scope of Services to be provided under this contract.
d. Geology scope of services will be limited to the Group A dams.
e. Environmental scope of services will be limited to the above mentioned dams. Training activities were provided by the domestic Environmental Specialist.
f. The Social Component scope of services was limited to Group A dams. The PCU provided a previously completed socio-economic assessment of the Sana'a Basin to the Stanley Consultants team.
g. Three dams were removed from the scope of works – Thoma, Tozan, and Bayt Shaiban.

The removal of some of these items impacted the required training and workshop contents. No discussion of construction supervision or hydrogeology was given during the workshops and training activities.

2.3 Activities Reassigned to Other SBWMP Project Components

During negotiations, the PCU advised Stanley Consultants of the following additional changes in the Scope of Services. The following tasks originally envisaged under the Dam Design program were given to other SBMWP project components. For this reason, input related to these areas was not considered necessary by the PCU.

- Water quality surveys are already covered by other components. No further water quality surveys may be needed to be undertaken by the consultants.
- Groundwater modeling, aquifer monitoring and water balance studies are also envisaged under other components of the SBWMP project.

2.4 Review of Feasibility Studies and Reports

All members of the team have reviewed the six feasibility studies completed by Hydrosult in 2002. The detailed descriptions of each evaluation, by discipline, can be found within each Section.

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Sl No	Name of Report	Prepared by	Date of Submission
1	Feasibility Study of Al Malah Dam	Hydrosult	July 2002
2	Feasibility Study of Bahman Check Dam	Hydrosult	July 2002
3	Feasibility Study of Al Sinn Dam	Hydrosult	July 2002
4	Feasibility Study of Beryan Dam	Hydrosult	July 2002
5	Rehabilitation of Al Lujma Dam	Hydrosult	July 2002
6	Rehabilitation of Al Jaef Dam	Hydrosult	July 2002
7	Soft copies of all reports	Hydrosult	July 2002
8	Basin Characterization and selection of Pilot Study Areas-Volume II, Water Resources	Sana'a University Water and Environment Center and SBWRM-PPT	October 2001
9	Basin Characterization and selection of Pilot Study Areas -Volume III, Resources and Environmental assessment	Sana'a University Water and Environment Center and SBWRM-PPT	October 2001
10	Basin Characterization and selection of Pilot Study Areas -Volume IV, Socio Economics	Sana'a University Water and Environment Center and SBWRM-PPT	October 2001
11	Basin Characterization and selection of Pilot Study Areas -Volume V, Back up data	Sana'a University Water and Environment Center and SBWRM-PPT	October 2001
12	Supply Management and Aquifer Recharge Study – Miscellaneous reports (1) Volume II	Hydrosult	July 2002
13	Supply Management and Aquifer Recharge Study – Miscellaneous reports (1) Volume III	Hydrosult	July 2002
14	Supply Management and Aquifer Recharge Study – General Reports Volume I	Hydrosult	July 2002
15	Supply Management and Aquifer Recharge Study – Final reports Volume I	Hydrosult	July 2002
16	Reports of well inventory in Sana'a basin-(Soft copy)	Sana'a University Water and Environment Center	January 2004
17	Topo Sheets of Dam Site Areas	Survey Authority of Yemen	1998
18	Regional Environmental Assessment Report, Executive Summary	Ministers Cabinet Capital Secretariat SBWMP, Republic of Yemen PPT. World Bank	November 2002
19	Regional Environmental Assessment Report, Executive Summary and Main Report	Ministers Cabinet Capital Secretariat SBWMP, Republic of Yemen PPT. World Bank	December 6,2002

20	Regional Environmental Assessment report, Annex Volume 1 Supporting Data and Information	Ministers Cabinet Capital Secretariat SBWMP, Republic of Yemen PPT. World Bank	November 21, 2002
21	Data Basin of Existing Dams in Sana'a Basin, Final Report Volume 1; Dam 1 to Dam no 22	Ministry of Agriculture and Irrigation	May 2001
22	Data Basin of Existing Dams in Sana'a Basin, Final Report Volume II; Dam no 23 to Dam no 44	Ministry of Agriculture and Irrigation	May 2001
23	Appendices, Volume.1 Climate and Hydrology, Part ii .Tables, Graphics and other Material	Ministry of Agriculture and Fisheries, v/o SELKHOZOPROMEXPORT USSR	1986
24	Appendices, Volume 2. Geology and Hydrogeology, Part II. Plots	Ministry of Agriculture and Fisheries V/O SELKHOZOPROMEXPORT USSR	1986
25	Social Assessment Study	Ahmed S. Gabali, Ministry of Planning and Development	March 2002
26	Project Appraisal Document	Document of the World Bank	April 23,2003
27	Social Assessment study	Ahmed S. Gabali, Ministry of Planning and Development	March 2002
28	Water Resources Management Options in Sana'a Basin-Final report– Volume IX	The Technical Secretariat of the High Water Council	June 1992
29	Regional Water Requirements for Different Water Consuming sectors-Final report – Volume V	The Technical Secretariat of the High Water Council	June 1992
30	Groundwater Resources, Part Two-Southern Governorates – Final report – Volume IV	The Technical Secretariat of the High Water Council	June 1992
31	Environmental Impact Assessment for Water Resources Planning Sector – Final Report – Volume VIII	The Technical Secretariat of the High Water Council	June 1992
32	Surface Water Resources, Final report – Volume III	The Technical Secretariat of the High Water Council	June 1992
33	Statistical year- book 2002	Ministry of Planning and International Cooperation Central Statistical Organization, Republic of Yemen	August 2003- Sana'a
34	Preliminary Results of Water Points Inventory, Midterm report	Sana'a University Water and Environment Center (WEC), Sana'a Basin Water Resources Management Study SBWRM-PPT	Sep 2002
35	Well –Inventory Data Nihm and Bani Hoshaish SBWMP	SBWMP	Jun-20-2006

36	Rationalizing Groundwater Reuse in the Sana'a Basin, Yemen	Stephen Foster	August 2003

2.5 Consultation and Collaboration

As stated in section 1.3, information on the Detailed EIA consultant and his tender were not available during the detailed design. The limited inputs available to the team have been used to complete the environmental issues relating to the Project.

The social survey teams from Stanley Consultants have closely worked with representatives from NWSA, Sana'a Branch, to obtain information regarding previous activities and NWSA's familiarity and data relating to the dam site communities.

During development of the dam designs, technical consultations with ARCADIS, PCU and GDI have been conducted with regards to the geotechnical program, design criteria and preparation of contract documentation.

Activities carried out during the detailed design have been described in detail in relevant sections in the report.

2.6 Activities and Achievements

2.6.2 Field Evaluations

Works Completed

- All six project locations have been visited and the general information regarding each location collected.
- All the topographical maps prepared by Hydrosult have been verified at site and attempts were made to identify the benchmark locations.
- Attempts were made to identify Hydrosult borehole and test pit locations at each site. Where successful, available data was collected and summarized.
- New topographical surveys were conducted on all sites. Permanent concrete benchmarks are now established at appropriate locations. All the topographical field works were initialized with the help of hand held GPS. The coordinates obtained from hand GPS have been counter-checked with Government Topographic sheets.
- General access maps of all project locations with respect to Sana'a SBWMP office have been prepared.
- Well location maps of all the sites have been prepared.
- General land use maps of each site have been prepared.

2.6.3 Topographical Evaluations

Works Completed

- Permanent concrete benchmarks have been constructed at all Group - A sites.
- Topographical surveys have been completed at all Group - A sites.

2.6.4 Geotechnical Evaluations

Works Completed

- Site Evaluation including field visits.
- Evaluation of Feasibility reports of Hydrosult
- Preparation of a site investigation program.

2.6.5 Geological Evaluations

Works Completed

- Review relevant geological data and previous studies.
- Assess geologic and geotechnical site conditions.
    - Evaluation of findings from the feasibility study and geologic maps.
    - Field work, to include updating the geologic maps.
- Geologic reconnaissance and mapping.
- Recommendations for dam rehabilitation from a geological perspective.
- Evaluation of materials sources needed for construction or rehabilitation of different types of dams.
- Recommendations for additional test pits and evaluations.

2.6.6 Surface Hydrology Evaluations

Works Completed

- Evaluation of dam sites and catchment area.
- Review of site conditions for evaluation of sedimentation and runoff potential.
- Data collection related to precipitation, stream gauging, evaporation measurement, and river and reservoir sediment measurement.
- Review of available hydrological data sources, reports and studies.
- Additional study, development and evaluation of the following data resources needed to complete the dam designs.
    A. Runoff volume studies.
    B. Studies for the safe design flood estimates of the dams.
    C. Reservoir sedimentation and evaporation estimates.
    D. Reservoir simulations studies.

A training session was held for three SBWMP/GDI candidates nominated by SBWMP. Syllabi and course materials were presented to SBWMP in advance of the training session. The session is briefly described in Section Thirteen of this report.

2.6.7 Hydrogeological Evaluations

Works Completed

- Site evaluation, including field visits.
- Evaluation of feasibility reports by Hydrosult.
- Preparation of hydrogeological maps.
- Collection of historical ground water level trends data near dam sites, if available.
- Identification of hydrogeological, economical and social benefits of study area.
- Identification of alternatives to hydrogeologic limiting factors.
- Negative hydrogeological impacts identification and solution.
- Establishing hydrogeological performance criteria.

2.6.8 Water Quality Evaluations

Works Completed

- The overall scope of the Water Quality Expert was reduced from the original Technical Proposal. Some of the tasks associated with water quality review, such as testing and monitoring, have been assigned to other projects in SBWMP program.
- Site visits to all project sites.
- Review of available data on water quality in the Sana'a Basin.
- Presentation of water quality observations from the available reports.

2.6.9 Environmental Evaluations

Works Completed

- Multiple visits to each dam site. Field visits and socio-environmental data collection work was completed.
- Environmental document review, and identification of data gaps.
- Broad categorization of positive and negative environmental impacts at the site.
- Review of the dam site's suitability for the construction of the dam with reference to archaeological and architectural structures; political sensitivity; and ecological sensitivity.
- A preliminary assessment (by meeting local community members) was made on various environmental and social impacts on water use, water quality, land use and agricultural practices in the reservoir existing areas.

- A review of the legislation was completed. Policies and existing laws were recorded.
- The potential positive / negative impacts of dam construction were recorded for each site.
- Establishment of contact with environmental Non-Governmental Organizations (NGO) working in the dam area, if any.
- Environmental analysis of various impacts
- Public consultation with local groups, including village local councils.
- Review of organizational structure and implementation practices of the available resources management agencies in Yemen.
- Recommendations for an Environmental Management Plan.
- Preparation of environmental tender document requirements.
- Detailed procedures are given in the report for the environmental consultant to carry out the detailed investigation and prepare an Environmental Assessment Report.
- Preparation and delivery of environmental training materials.
- Meetings with the PCU and other ministries for information dissemination.

2.6.10 Social Evaluations

Works Completed

- Collection and review of available reports and documents.
- Work and site visit plan preparation.
- Preliminary field visits to the targeted sites to interview community groups and observe the targeted communities.
- Coordination with the Agricultural Office in Sana'a to prepare for the field visits.
- Review and data gap analysis of information collected during preliminary visits.
- Meeting with Information and Public Awareness Campaigns Unit at Sana'a Basin Water Management Project.
- Development of public awareness campaign recommendations.
- Preparation of the questionnaire for individual interviews and checklist for group discussions in Arabic.
- Conducting data collection visits to the dam sites. Questionnaires were filled out and Participatory Rural Appraisal (PRA) techniques were conducted.
- Conducting meetings with different stakeholders in Sana'a, including SBWMP.
- Compilation and analysis of questionnaires and PRA data.
- Present recommendations for Public Awareness Programs to SBWMP.
- Conduct training workshops for community representatives and stakeholders.

2.6.11 Review and Design

Works Completed

- Reconnaissance field visits.
- Arrangements for data collection.
- Detailed data collection and verification.
- Review of available data and previous studies.
- Assessment of dam sites based on the previous study and the output of the field reconnaissance.
- Preparation of topographic survey for all dam sites and reservoir area.
- Preparation of specifications and tender documents for the additional geotechnical investigation work.
- Evaluation of alternative dam types.

Detailed analysis of the design process regarding the check dams, can be found in **Section 9**. A general description of the design process can be found at the end of this section.

2.6.12 Seepage Analyses

Seepage analysis for check dams is not applicable.

2.6.13 Drawings and Tender Documentation

Detailed construction drawings and bid documents were prepared. Detailed bills of quantities and cost estimates for the construction of all new dam and rehabilitation of existing dams were also completed. The cost estimates for material items were generally based on applicable rates provided by GDI. These GDI rates reflected costs of similar works completed in the Sana'a Basin, or nearby sites, in recent times.

SECTION THREE: SITE EVALUATION

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SECTION THREE: SITE EVALUATION

3.1 Topography

The project sites for the new Bahman check Dams are located near Bahman village in the Beni Hushaish District in the Sana'a Basin. The UTM coordinates of the Bahman dam site are 442632 Easting and 1717351 Northing. This village is approximately 41.40 km from Sana'a. The access road to Bahman is a mixture of paved and unpaved conditions. The first 31.50 km of the access road is paved, and the rest is an unpaved road that traverses through the wadi bed before reaching the village. Around 8km of the unpaved section used to be a good paved road. Due to a flash flood in the main wadi, this section of the road surface is washed out on several places. So now the wadi is used as access road.

The total catchment area of Wadi Bahman from the highest point until it joins Wadi Al-Sirr is almost of rectangular shape, consisting of two ridges running along the right bank and the left bank of the main course of the wadi. The Bahman wadi is a tributary of Wadi Al-Sirr. In general the catchment area is mountainous, with steep slopes and barren rock having a fall of about 300 m over a length of 5 km. The dominant type of bedrock in the Bahman valley is sandstone.

The Bahman watershed is located in a hilly region; it consists mainly of steeply sloped hills which cover around 65 % of the watershed area. Hillsides are covered with weathered rocks and bare soils. The watershed has an elongated shape, and it is formed with three sub-watersheds. The watershed possesses an intensive drainage network.

The main channel is located in a narrow U-shaped valley. The remaining part of the water course, where the construction of series of check dams is proposed, crosses a relatively wide valley .The alluvial deposits in this part of the wadi are generally coarse and composed mostly of coarse sand, gravel and pebbles.

The project area in the wadi contains a highly weathered sand stone formation. The entire portion of the wadi is filled with alluvial deposits with big boulders and stones. No agricultural lands exist in the upper part of the watershed. Terraces are extensively developed in the middle and lower part of the watershed and proposed site area.

3.2 Site Features and Conditions

The unpaved section of the road from Village Baid Al-Enab is narrow, bumpy, and features many elevation changes. The proposed 26 check dams are spread out over 4.5km of the wadi. The locations of these check dams are most favorable in the middle to the lower lengths of the wadi, where alluvial deposits are found over sandstone. Construction of check dams in the lower region of the wadi is likely to be more economical and effective for aquifer recharge, and it would be an excellent vehicle to engage local communities in practical action for water resources conservation. The series of proposed check dams also has the advantage of tending to trap silt in the first structures upstream, and allowing clearer water to pass downstream. The wadi bed infiltration rate will be considerably enhanced in these lower check dams. The lower check dams will also check the floods very effectively due to the anticipated lack of sedimentation.

3.2.1 Land Use

Five villages are located near and around Wadi Bahman, with a total population of 4,500 people. Agriculture development is hindered by a water shortage in the wadi, even though the Bahman watershed is relatively rich in runoff water. The main economic activity of the population is agriculture, as more than 90% of the community are farmers, shepherds, or involved in activities related to agriculture and herding. The main cash crops are qat, grapes, fruits and vegetables.

Agricultural farms are observed on both sides of the wadi. Major parts of the catchment area have been developed as terraces for grape and qat farms. The farming communities along this wadi are well aware of the need to harvest wadi storm flows. In addition to the farmland, habitation is also observed on both sides of the catchment area.

The lower part of the wadi is now used as an access road as described earlier. This access road traverses through Baid Al-Enab and Bahman villages. There are 5 existing check dams that have been observed within the wadi's project area. These check dams appear to have been constructed by local groups without the benefit of professional engineering support or supervision. The future reservoir areas of these existing check dams are completely covered by gravel deposits. The villagers dump rock pieces and boulders excavated from their farms into the wadi bed.

Water for domestic use is generally free, but for irrigation purposes it costs 1,500 YR per pumping hour. Water User Associations operate shallow wells and tube wells. In general, there is an awareness of the water shortage in Wadi Bahman, and the local communities are in full support of check dams. These communities are willing to give away land without claiming compensation because the dam sites are lands in common ownership.

3.2.2 Wadi Flooding Conditions

As per the information from the villagers, the wadi is affected by flash floods 4 to 5 times each year. These floods produce water flow of at least 1 meter deep, and the floodwaters remain in the wadi for a maximum period of 2 to 3 hrs. There are 12 open wells and two bore wells with pumping stations along the 4.5km-long check dam site. The wells appear to have a good yield. 10 wells are operational, and the pumping stations produce water from the wells daily for a period of 5 to 12 hours.

3.2.3 Review of Feasibility Study Check Dam Locations

Stanley Consultants' team marked all of the check dam positions proposed by Hydrosult in the wadi. The team has tentatively located an additional five check dams. After reviewing the benefits of each location with the technical consultant, AEC, and GDI, a total of 26 check dams were proposed at the project site. The heights of these check dams will vary from 1.50m to 2.00m. Construction of the check dams was proposed in stages during the feasibility study. Hydrosult proposed to construct 12 check dams out of 23 check dams in the first phase. The phasing and construction of these dams will be reviewed as the project progresses.

Some of the check dams proposed in the feasibility study were located very close to each other. These check dams were relocated in order to optimize their efficiencies and reduce costs. There is very good positive approach towards the dam construction from the side of the villagers. As per the Hydrosult report, no borehole and test pits were conducted in Bahman. The materials visible at the site, and in borrow pits north of the wadi, appear to be appropriate and of good quality to build check dams.

The selected sites for check dams do not face any social constraints provided that these dams are built by the government. Also, the local communities appreciate the benefits of these dams for groundwater artificial recharge. The positive environmental impacts are additional water for domestic and agricultural use, increased employment of people living near the check dams, and improved flood control. The local villagers have mentioned that they also want to construct a larger dam in this wadi. There are two ideal positions for larger dam construction, one at the beginning of the check dam area, and one at the end of the check dam area. A large quantity of water can be stored in either location. The design of such a larger dam is beyond the scope of this project.

Our initial recommendation for maintenance of all the check dams would be to remove the alluvial sediment, fine sand, silt, clay and organic material that accumulate behind the check dams. Removal of this material would restore the infiltration capacity of the wadi floor. The material removed can be used as a top-dressing for agricultural soils.

3.2.4 Construction Labour Camp

The construction labour camp for the Bahman dam site is proposed to be located at the entry point of the access road. This area will not be affected by the flood water. Sanitary waste can be disposed at that location by providing soak pits. There are facilities for electricity and water supply. A contractor could obtain electricity from the nearby village. Approximately 300 m of extra electric line would be required. For water service, approximately 400 m of pipeline would need to be laid from Bahman village to the proposed labour camp site.

Raw materials and a labour force for dam's construction would be provided at the dam sites by the adjacent communities. These communities are willing to provide trainees for training on operation and maintenance of these dams. However, good connection roads between the villages and the wadi check dam sites would be needed in order to take full advantage of the communities' goodwill.

3.3 Site Access

This village is approximately 41.40 km from Sana'a. The access road to Bahman is a mixture of paved and unpaved conditions. The first 31.50 km of the access road is paved, and the rest is an unpaved road that traverses through the wadi bed before reaching the village. Around 8km of the unpaved section was in a good paved road earlier and due to flash flood on the main wadi the road formation is washed out on several places so now the wadi is used as access road. The unpaved section of the road from Village Baid Al-Enab is narrow, bumpy, and features many elevation changes. A large number of steel and HDPE irrigation pipe lines cross the access road near the farms. These pipes provide water from the wells to agricultural fields on either side of the wadi bed. These pipelines are resting on the ground, and they will require protection from heavy vehicles and equipment during construction. Construction of a new access road will be necessary for the movement of the villagers along the wadi.

There are some site issues that must be addressed before and during construction. The access road to the site traversing through the village is very narrow. It may be difficult to move construction equipments and trucks to the site, as some portions of road are traversing through the habitation area of the village. The contractor will have to verify that his equipment can pass along the access road without damaging existing buildings or structures.

3.4 Topographic Survey

The Stanley Consultants team completed the topographic survey in the Bahman dam site with greater accuracy and established permanent benchmarks near the wadi. These new benchmarks consist of concrete pillars with a steel rod. Topography surveys were undertaken in this project specific to all dam sites, to ensure greater accuracy than was available. Total stations were used with reference to local benchmarks. This new survey's objective was to produce up-to-date conditions at the dam sites with a contour interval of

1m and survey accuracy in all direction of 1cm in 100m. For the Bahman dam sites, the ground survey covered the entire series of check dam locations along a 5km length.

A detailed survey map was prepared showing all required details such as wells, pumping stations, trees, houses, road, geologically important points, etc. The detailed topographic survey map is included in Volume III, Drawings. The exact values of the new benchmark locations are furnished in the table below.

Table 3.1. Stanley Bench Mark Details

BM 1

Location - On the top of the rock formation on the left bank, around 100m away from the wadi.
Northing - 1716938.000
Easting - 442642.000
Elevation - 2401.000

BM 2

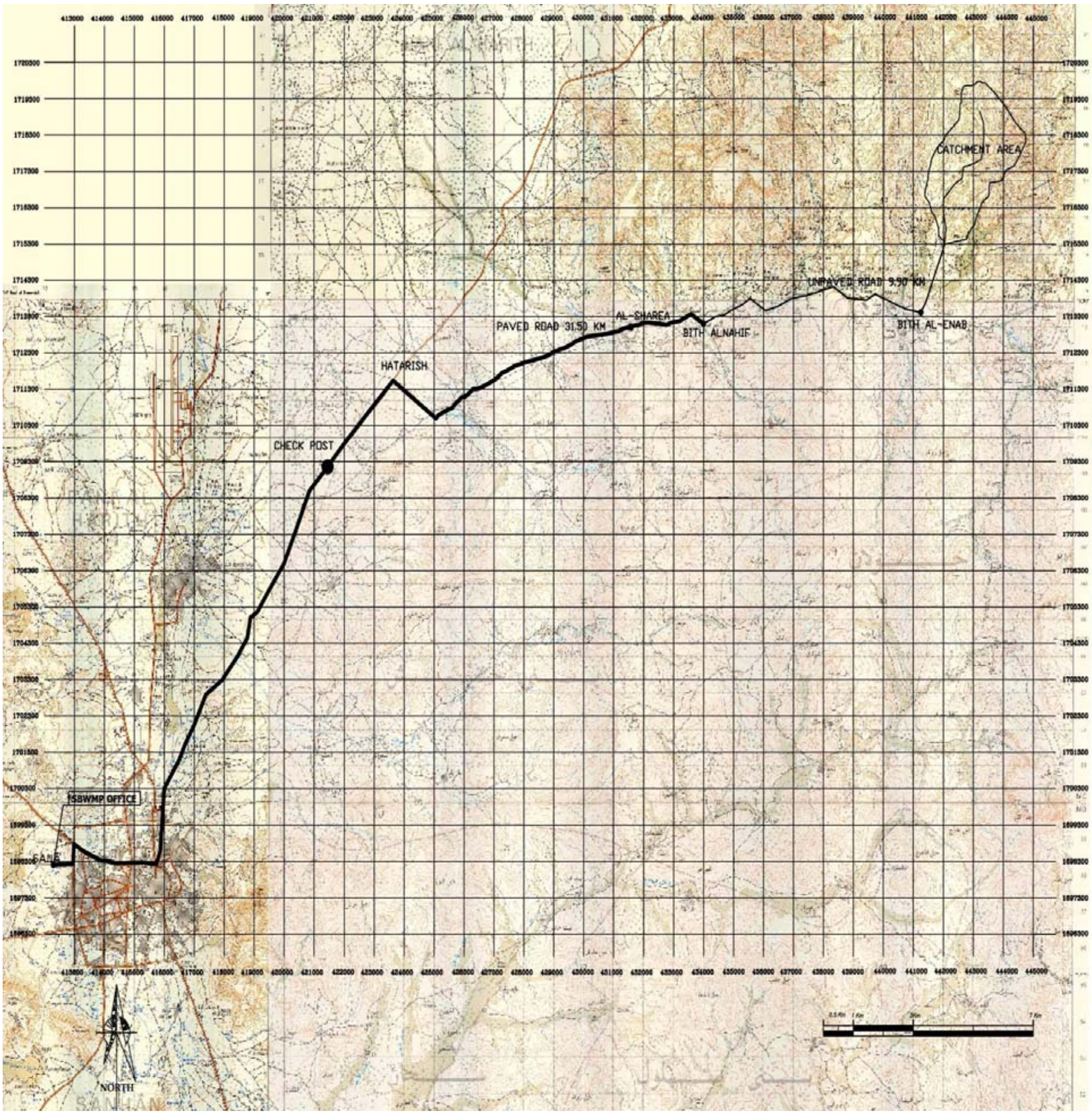
Location - On the top of a small rock formation on the right bank.
Northing - 1717041.729
Easting - 442398.695
Elevation - 2382.027

3.5 Geotechnical Investigation

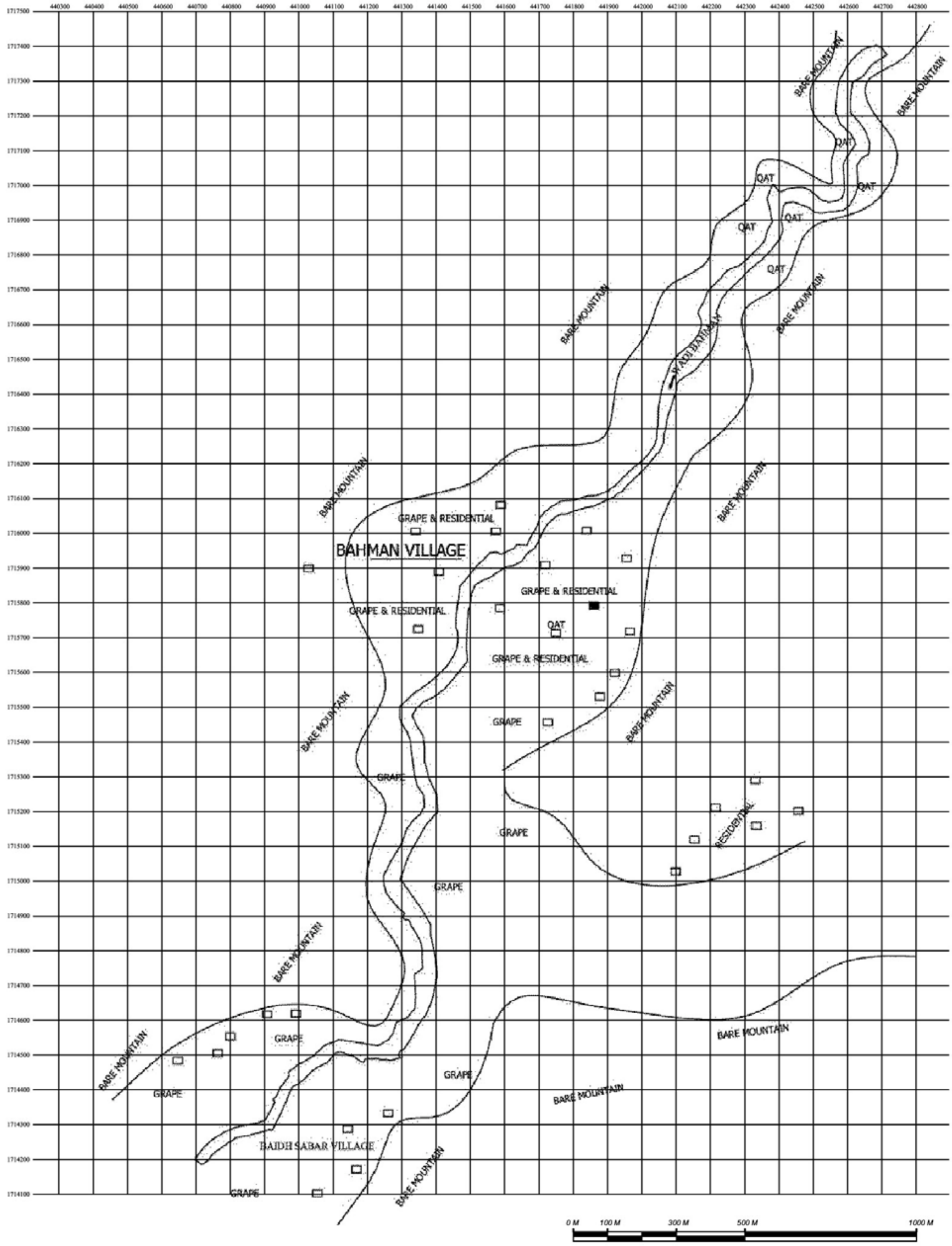
No geotechnical investigations were carried out for this dam site.

3.6	Annexes

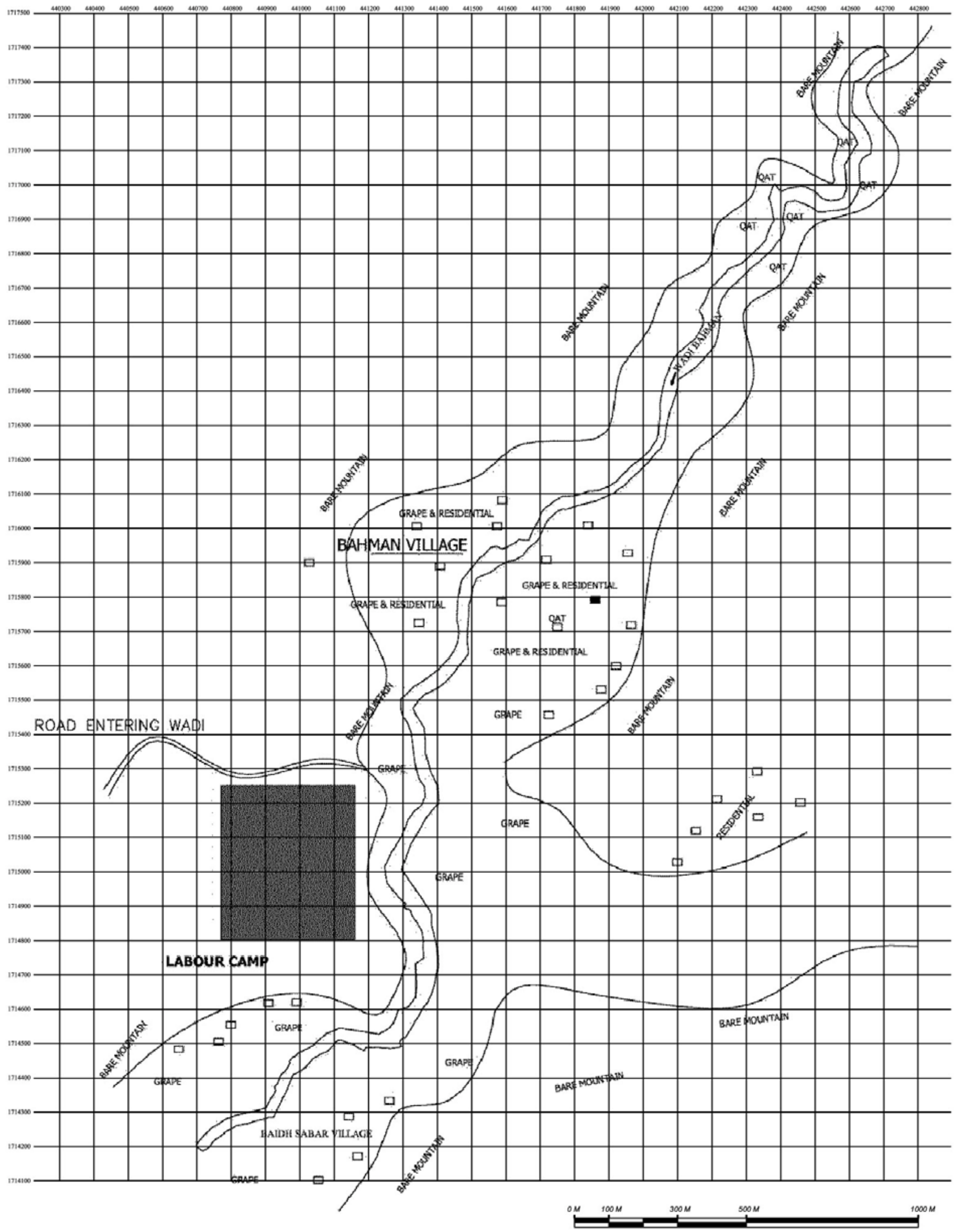
3.6.1 Site Access Map



3.6.2 Land Use Map



3.6.3 Labour Camp Location Map



SECTION FOUR: SITE GEOLOGY

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SECTION FOUR: SITE GEOLOGY

4.1 Introduction

This section describes the geologic and site investigations conducted in November 2005 and January 2006 at the site for the Bahman Check Dams. These investigations are part of the overall detailed design activity, and review of the feasibility study conducted by Hydrosult in July 2002. The general geological situation was explained simply and clearly in the feasibility study report. The proposed check dams are small structures, no more than a couple of meters high. All the check dams are located within the banks of the main water course to augment both wadi bed and field level infiltration.

The location of these check dams are favorable in the middle and lower parts of the wadi where alluvial deposits overlie the sandstones. They are economical and effective in terms of alluvial recharge. The alluvial deposits are composed of coarse sand and gravel, and they are highly porous and excellent for recharging. The thickness of these deposits ranges from 2m at the upstream side to 9m in lower part of the wadi.

4.2 Geological Considerations

Relevant data for the Sana'a Basin Water Management Project was collected from the Ministry of Water and Environment. This information was reviewed along with the Feasibility Study Report for the Bahman Check Dams. The general types of explorations conducted by during the feasibility study to investigate the project fall into two categories:

i) Geological reconnaissance and mapping
ii) Geophysical Measurements.

In this context, the report highlights the aspects with particular importance on the site geology. The general geology of the site shows that the rock outcrops are of sedimentary origin. They consist of the wadi deposits and sandstone strata of Cretaceous age. The recent sediments consist of artificial deposits, alluvial and colluvial materials. The main geological formations in the Bahman check dam area are summarized as follows:

4.2.1 Overburden

These superficial deposits are relatively young. Most likely, the have accumulated in recent times and now overlay the bedrock. Generally, these deposits are derived from bedrock in the vicinity of the wadi, and they are transported by water, wind, rolling or other gravity actions. The overburden is then deposited at the wadi channel. These deposits are varying in nature and thickness. They can be classified as artificial fill, alluvium, and talus.

4.2.2 Artificial Fill

Artificial fill is located at both sides of the wadi course, or it may be restricted to one side in the area where the wadi is too narrow. These materials are cultivation terraces which have been constructed along the wadi. These terraces are protected by stone walls from any floodwaters that may occur during storms in the rainy season. The construction methods used in building these walls and terraces are typical of the region. **Plate 4.1** shows an existing check dam. The thickness of the alluvium material is not clear, since there is no data available about the base of this material. It is not known if the check dam was constructed atop bedrock or alluvium.

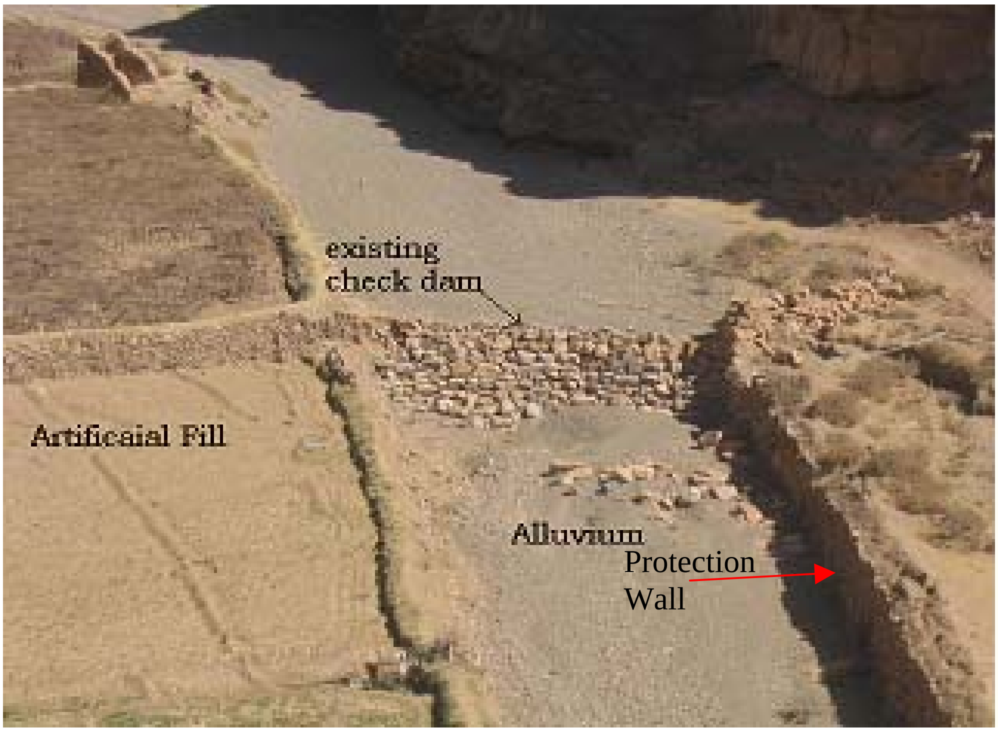

Plate 4.1: Downstream of Check Dam Area.

4.2.3 Alluvium

The alluvium material is found in the wadi channel, as shown on **Plate 4.2**. The estimated maximum thickness of deposits varies from more than 2m in the upper part of the wadi to about 9m deep in the lower portion.

In the location of the electrical profiles conducted during the feasibility study, the dry alluvium deposits exhibit resistivities that vary from 2 to 2775 ohm. The wide range in resistivity values is related to the composition of the weathered layers. These layers extend along the wadi profile with thicknesses varying from 4m to 6m at the edges of the wadi.

Plate 4.2: Alluvium Material Upstream Bahman Wadi.

4.2.4 Talus and Slope Scree

Most of the hillsides are covered with slope scree and/or a thin skin of sandy soil where the talus materials have accumulated at the hillside toe. This condition is shown in **Plate 4.3**. These materials should be removed from the designed footprints of the check dams.

Plate 4.3: Slope Scree and Talus Deposits at Hill Slope.

4.2.5 Bedrock

In general, the hillsides of the Bahman site are composed of sandstone of the Cretaceous age. The general mapping along the wadi channel shows that the sandstones are well exposed. The exposed sandstones show well developed cross beddings with occasionally pebbly layer at the base of the main bed.

This sandstone belongs to the Tawilah Group of Cretaceous age (Hauterman-Maastrichtian) with a total thickness of 600 to 700m. The sandstone rests directly above Jurassic rocks with stratigraphical unconformity; it is overlain with tertiary volcanic rocks. **Figure 4.1** shows the stratigraphic position of Tawilah Group.

The group consists mainly of red colored, coarse sandstone intercalated with siltstone, marl and shale. These intercalations have limited extent and spread out laterally. The sandstone is poorly cemented in general; and some locations it is friable. A small number of localized areas exhibit well cemented stone.

The proposed check dams will be constructed in different locations across the wadi channel. In most of the cases thick alluvium material cover the bedrock, only in few locations the sandstone is exposed in the wadi course. It is also noted in most of the cases that both abutments are stone walls of the cultivation terraces and some locations are in the narrow channel areas. Sometimes, one of the abutments will be against the stone walls and the other abutment will be against talus material.

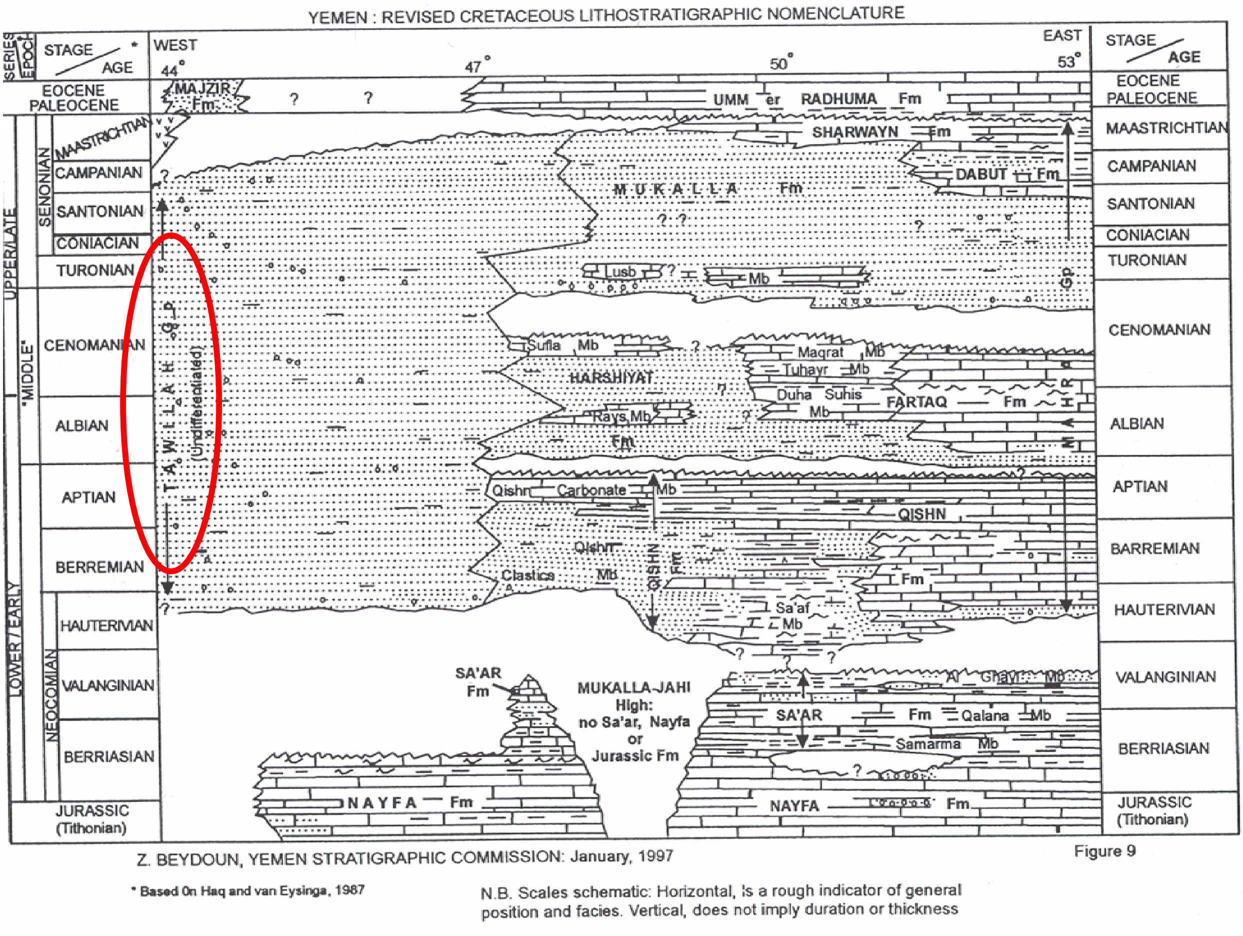

Figure 4.1: Stratigraphic Position of Tawilah Group

4.3	Geotechnical Considerations

No significant geotechnical investigations appear to have been performed during the feasibility study. Geophysical surveys and geoelectric sections were completed as part of this work. Two sieve analyses were performed upon soils found at the site at sections D and R of the Hydrosult drawings. Shallow test pits were dug to obtain these samples at a depth of 1m.

No additional special considerations are required for the check dams. Sufficient material for construction of the check dams can be found along the wadi shoulders. This material is of good quality as described in the geologic discussion above. No geotechnical obstacles or challenges are expected in the construction of these check dams.

SECTION FIVE: HYDROLOGY

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SECTION FIVE: HYDROLOGY

5.1 Introduction

The Sana'a Basin is located in the central highlands of northern Yemen. It includes the capital city of Sana'a. The basin has an area of 3220 km^2 and an average elevation of 2200 m above sea level. The current population of the basin is about 1.5 million, out of which 300,000 people live in the rural areas. Arable land within the basin is approximately 110,000 hectares (ha), of which 24,000 ha is currently irrigated. The main source of irrigation is the extraction of groundwater by surface wells, as well as deep tube wells.

The Sana'a Basin is experiencing a serious problem of depletion of groundwater; this has been accompanied by an associated degradation in water quality. Since 1980, groundwater usage has exceeded the available recharge. This deficit has occurred through unlimited abstraction of water via pumped wells. Abstraction is uncontrolled, unmetered, unlicensed and no payments are required from the well owners for this water. There is no management plan for the Sana'a Basin at this time. No regulatory framework exists for the management of the groundwater extraction and inefficient irrigation practice. Unless immediate remedial measures are taken to improve the basin aquifers, current level of water depletion will create major crisis relating to availability of water for various purposes including irrigation and water supply. The government of Yemen is well aware of the fact and is taking steps through the Sana'a Basin Water Management Project (SWBMP).

In order to overcome the pressures on the water supply within the Sana'a Basin, The Government of Yemen and the World Bank prepared the SWBMP. The SBWMP seeks to address this problem by increasing both quantity and quality of groundwater by construction of dams or a series of check/detention dams across wadis within basin and simultaneously increase the efficiency of the agriculture water use so as to allow for a gradual shift to a less water based rural economy in the basin.

The Sana'a Basin is hydrologically self-contained. Outflows occur only in the instances of heavy rainfall for a long duration, which is rare. There is no perennial water in the wadis. Local observations reveal the wadis flow for short durations--a few hours after a rainfall event--and the wadi bed becomes dry soon thereafter. The length and the duration of the wadi flow are influenced by the antecedent moisture conditions of wadi bed and catchment. Average annual precipitation in the basin is 155 mm, in the direction of east to west. In the catchment areas of the above mentioned projects, the annual precipitation is slightly lower. The groundwater configuration has two major strata; a shallow aquifer (alluvium and volcanic), with depths from 30 m to 70 m; and a deep aquifer with depths between 100 m to about 1000 m. These aquifers are reportedly not connected; actual depths and thicknesses of the aquifer varying between the project sites.

5.1.1 Wadi Bahman as Pilot Project

At this time, there has not been a comprehensive program to implement and monitor a series of check dams in Yemen. It is possible that check dams represent the most viable solution for future groundwater recharge schemes in Yemen. The initial costs and lifecycle O & M costs of check dams are less than larger, gravity dams; check dams can be easily maintained by local water user associations or community groups; and they can provide locally directed recharge to support agricultural activities and well recharge within a wadi or catchment area.

In order to realize Wadi Bahman as a successful pilot project, the monitoring component will be essential. It is important that the Project Coordination Unit (PCU), GDI, and other responsible organizations work together to properly maintain, record and safeguard data, and evaluate the performance of this project.

A detailed monitoring plan for the Bahman Check Dams can be found in Section 14. Additional discussion and recommendations for monitoring and data collection activities can be found elsewhere in this Section.

5.1.2 Project Objective

The overall purpose of the Bahman Check Dam project is to improve and maximize recharge within the wadi and catchment area. The optimization of this recharge will be obtained through the design and location of the new check dams (Section 9); appropriate environmental considerations and environmental management (Section 10); engagement of the local community and public awareness programs to improve human management of the wadi (Section 11); and proper monitoring of the check dams and instrumentation present in Wadi Bahman (Section 14). Additionally, this project may serve as a pilot project for check dams in other locations in Yemen as noted above.

5.2 Summary of Activities and Review of Documents

Data collection was a challenge throughout the entire project. Hydrologic data, when it is available, is often unreliable, incomplete, or contains errors in the data. Data sets that were obtained during the course of this project required careful evaluation to determine any adjustments that might be required to make them usable for design consideration.

In this regard, assistance and collaboration was sought from the technical consultant to the PCU, Arcadis Euroconsult (AEC). AEC has considerable, long term experience in hydrological projects within Yemen. This experience has allowed AEC hydrologists the opportunity to review and make technical assumptions about the reliability of data that is available. AEC provided sources of data to our team for the purposes of more accurately evaluating information such as rainfall, runoff, and generation of the unit hydrographs required for design criteria generation. Collaboration with the other dam design consultant, Halcrow, was obtained for the purpose of document review and coordination on hydrological procedures.

Data and documents that were reviewed during the course of the project include the following items.

1. The daily rainfall data at the following stations:
   a. Sana'a airport (station ID 384): From the year 1970 till date, as available.
   b. Similar rainfall data for other rain fall stations, from the year 1991 till date:
      i) Birbas'l - A (station ID 477)
      ii) Samnah (station ID 478)
      iii) Ma'adi (station ID 487)
      iv) NWRA - A (station ID 305)
2. Records of short duration rainfall bursts, i.e. the maximum recorded rainfall in 1/2 hour, 1 hour or 2 hour duration or for the durations as available.
3. Stream flow gauging records, i.e. gauge and discharge measurements anywhere in the Sana'a Basin near project sites of our interest. Details and procedures of this measurement were reviewed.
4. Sediment measurement details.
5. Evaporation measurements, details of procedure of measurement and data for the period of availability.
6. Feasibility Study Final Reports. These reports furnished a short summary of the methodology used in hydrological calculations, and reported the results. The details of the data and computational details of the study and results were not available in the reports.

Without this information, it was not possible to understand the methodology, approach, and accuracy present in the runoff, design flood values, and reservoir simulation tables. Some of these items did not appear to follow established model guidelines.

7. The SCS RRM model of the High Water Council.(UNDP - DESD Project Yem/88/001)
8. Intensity Duration Frequency (IDF) Curves at Bani Matar.
9. Hydrological information generated by AEC.
10. Sana'a University WEC studies.
11. USSR study - Sana'a Basin water Resources Scheme. Climate and Hydrology

The SCS-RRM model was useful in evaluation of the hydrological studies. Apart from the description of surface water resources in the Northern Sana'a containing Sana'a Basin, this document gave important informative details of the SCS-RRM Model and recommendations for its application in Yemen. This document also contained information on the classification of catchments in both runoff-producing and runoff-absorbing zones; the application of curve numbers (CN value); Antecedent Moisture Content and K values for determination of the soil storage capacity, which ultimately determines the runoff volumes.

5.2.1 Local Observations – Check Dam Performance and Water Storage

There is a relative lack of reliable, consistent hydrologic performance data available within the Sana'a Basin. For this reason, a short section on local observations has been provided. While some of this information is anecdotal in nature, it may provide additional insight into the water recharge conditions, water events in the wadi, and the relative water levels evident in wells near the dam site.

Five villages are located near and around Wadi Bahman, with a total population of 4,500 people. Agriculture development in the area is hindered by a water shortage in the wadi, even though the Bahman watershed is relatively rich in runoff water.

Local information revealed that the wadi is affected by flash floods 4 to 5 times each year. These floods produce a water flow of at least 1 meter deep, and the floodwaters remain in the wadi for a maximum period of 2 to 3 hrs. Soil erosion in the wadi banks is evident, and this erosion is accelerated during periods of flood. Farmers and local residents indicated there is a need for soil protection techniques to be implemented in the area

There are 14 open wells and two bore wells with pumping stations along the 4.5 km-long check dam site. The wells appear to have a good yield. Ten wells are operational, and the pumping stations produce water from the wells daily for a period of 5 to 12 hours.

Ground water is most often extracted through boreholes. Six collectively-owned boreholes are found in the village with depths that vary between 300-400 m. Local knowledge tells us that the wells have experienced an annual decrease in the water table level of approximately

5-6 meters. Surface water flows are found in the branches of the wadi. Many of the surface wells have dried up and no longer produce water.

Five existing check dams have been observed within the wadi project area. These check dams appear to have been constructed by local groups without the benefit of professional engineering support or supervision. The reservoir areas of these existing check dams are completely covered by gravel deposits, which affect their ability to promote recharge in the wadi. Our initial recommendation for maintenance of all the check dams would be to remove the alluvial sediment, fine sand, silt, clay and organic material that accumulate behind the check dams. Removal of this material would restore the infiltration capacity of the wadi floor. The material removed can be used as a top-dressing for agricultural soils. This could be accomplished by local farmers as the first step of a maintenance program.

Additional information about the water management practices, water availability, and social mechanisms in place in the villages near Wadi Bahman can be found in Section Eleven, Social Issues.

5.3 Physiography and Climate of the Sana’a Basin

5.3.1 Physiography

Northern Yemen is physiographically divided into three geographic units. These are:

A. Western Escarpment.
B. Eastern Escarpment.
C. Southern Escarpment.

This division may have formed because of the central mountain ridge running south to north within the high land region; this ridge is one of the influencing factors on precipitation patterns.

The Sana’a Basin is located within part of the central highlands, which is a part of the Eastern Escarpment.

5.3.2 Climate

The climate of Yemen is determined by the country’s geographic location at the southwestern corner of the Arabian Peninsula, and by the highly articulated relief, which rises from sea level to elevations of 3700 meters above mean sea level, within a distance of 100km.

The country is located in the border area of two systems of atmospheric circulation:

- From May to September, the climate is mainly influenced by moist air masses of the monsoon circulation system. This system flows from the southwest against the Yemen highlands, and it causes heavy precipitation on the mountain slopes exposed to the west. These slopes are primarily above 1500 meters in elevation. The rainfall events are characterized by high intensity, short durations, and localized extent.
- From October to February, dry air masses originating from the Central Asian Anticyclone provide a clear, rainless winter season.

The Sana'a Basin is located in the central part of the Yemen highlands. Absolute elevations vary from 2000 to 3000 m above mean sea level, with isolated mountain peaks at elevations of 3200 to 3600 m above mean sea level. The inter-mountain plains are interrupted by numerous wadis. The climate of the Basin is subtropical, mild and moderately continental. Evaporation exceeds precipitation. Under these conditions, irrigation and surface water runoff are the primary resources for agriculture. To a very limited extent, it is possible to grow rain-fed crops within the Basin.

The average annual precipitation of the basin is about 155 mm. This number is based upon evaluation of rainfall data by AEC in 2006. The hottest month is July, with average temperatures of the order of 22 to 24 degree Celsius. The average annual temperature ranges from between 12 to 20 degrees Celsius. Average monthly relative humidity varies from 35% to 55%. Mean annual duration of sunshine hours is 9 hours per day. The average maximum wind velocity is 11 - 13 meters per second in winter, and 13 – 15 m/sec in summer. Evaporation from the water surface is about 2,500 mm annually.

The rainy days are spread mainly from March to August. Annually, the number of rainy days range from 25 days (maximum) to 6 to 10 days (minimum).

5.4 Hydrological Studies

5.4.1 Objective of the Hydrological Studies

The hydrological studies aim to define the following hydrological parameters:

- Daily, monthly, and annual runoff volumes in the catchment area related to the upstream of the check dams. This study aims at the hydrological evaluation of the proposed sites. This will give an indication to the inflow volume to the Bahman Wadi.
- Design flood at downstream of the check dams; this is required for the design of the check dams and to confirm the size of the rocks, which can be used in constructing the check dams. The flood was estimated up to the last check dam at downstream of the wadi in order to have accurate estimation of flood flow for all check dams.

5.4.2 Hydrologic Data Availability:

Hydrologic data in Sana'a Basin is scarce. As explained above in **Section 5.2** above, many attempts were made to obtain the related hydrometeorologic data for the studies of the projects. This information was not available. In the various documents and studies, it has been stated that the data network and the duration of observation; except for a few rain gauge stations is extremely sparse. There are no hydrometric stations in or around the projects of our interest.

A total network of 19 rain gauges existed in Sana'a Basin at varying periods but not simultaneously; but except for Sana'a Air port and now at NWRA, the data availability of rain gauges is only for 3 to 7 years. Most of these stations are not operating. It was also not possible to obtain the daily rainfall data of the period from 1994 to 2004, so that the existing rainfall of the period from 1974 to 1993 could be supplemented for a 30 years period. Therefore the water availability studies had to be based on the rainfall data of the Sana'a rain gauge as available in Hydrosult's feasibility report.

Short interval stream gauge and stream flow measurements and historical storm analyses, required for computation of design flood are also not available. As such recourse had to be taken to other methods of computation of design flood and use synthetic unit hydrograph for designing the inflow flood hydrograph.

There is no Class A evaporation pan in the Sana'a Basin. The Sana'a Airport Meteorological station possesses meteorological observations. Estimation of evaporation in Sana'a Basin was based on evaluation of potential Evapotranspiration (Etp).

5.4.2.1 Surface Characteristics of Catchment Area

Bahman Check Dams

The Bahman wadi is a tributary of Wadi Al Sirr. A series of 27 check dams, of different heights between 1m and 3m, are designed to be constructed on the main water course of Wadi Bahman in order to catch the flow volumes for the detention and enhance the groundwater recharge. This is in addition to six existing, locally constructed check dams within the wadi. The catchment has a slightly elongated shape; its left flank is steeper in nature. In general, the catchment is surrounded by steep hill slopes. The elevation of the upper most point is approximately 2750 m, and the lowest point at the far end is about 2335 m. The dominant geology of the area is characterized by sandstone. The alluvial deposits in the flatter portion of the catchment are generally coarse composed mostly of coarse sand and gravel and pebbles. The main wadi originates at the level of about 2750 m as mentioned above, and the wadi bed at the last check dam is approximately 2322 m. The wadi size is rectangular in shape, at some places natural, but at many places it has been altered by construction of stone pitching walls to create qat fields. Pumping of surface and bore wells was in evidence, with surface wells reporting water levels at a depth of 30 meters below the ground surface.

The total catchment intercepted at the last check dam site is 10.16 sq. km. The length of the main wadi is 4.8 km. Over the catchment, the mean annual rainfall is about 155 mm. It is reported that the wadi flows for a period of 2 to 4 hours in the case of heavy rainfall, with a frequency of 4 to 5 times in a year.

A catchment plan for the Bahman area can be seen at **Figure 5.1**.

5.4.3 Estimation of Runoff Volume

The estimation of runoff volume (daily, monthly, and annual) for all the projects in the present study is based on the SCS-RRM Model (Rainfall Runoff Model using US Soil Conservation Service Method), previously developed by the High Water Council (UNDP / DESD Project YEM /88 /001).

5.4.3.1 Description of the Model

The High Water Council, in light of the stream flow data inadequacy problem, has suggested the application of a model which can compute runoff from rainfall records. Review of the DESD study noted above revealed that this study was intended to be used as national water planning tool. The High Water Council UNDP DESD project study further suggested the adoption of the SCS RRM model as such a model, and they have shown the applicability of this model in several wadis. This model has been suggested for use in both small and large catchments. The HWC model was developed upon similar principles developed by United

States Soil Conservation Service model. This model works on the principle of specific Curve Numbers (CN Values) which define soil moisture storage. This storage is also dependent on Antecedent soil Moisture Conditions (AMC), and it then computes the runoff from rainfall incidences. Thus, the selection of the curve number is crucial to the estimation of runoff. Proper curve number selection will involve some experience with, and knowledge of, site specific conditions as well as corroboration with the general trends of stream flows at site. For the adoption of different curve numbers, the report contains recommendations to classify the catchment into different categories, such as Runoff Producing Zones and Runoff Absorbing Zones. These zones can be further subclassified depending on geology and land use.

The SCS-RRM model aims to estimate daily runoff volumes from daily rainfall. The model is distributed one, with rainfall inputs applied to a number of distinct rainfall zones throughout a catchment, and with different "Runoff Characteristic Zones" (ROCs) separately treated within each rainfall zone. This distributed approach is believed to provide the best representation of the catchment's response to rainfall for the semi arid conditions experience within Sana'a Basin.

The ROCs are generally classified according to similar physical characteristics in areas such as geology and land. The different ROCs represent different response patterns of the soils in transforming rainfall to direct surface runoff. The model simulates the effect of daily rainfall on different types of soil and land surfaces, within a catchment, through the appropriate classification in ROCs.

In general, this method of SCS-RRM modeling distinguishes main runoff zones in the following manner.

- Runoff Producing Zones - Five Categories
  - (i) P1 : Steep Barren Rock
  - (ii) P2 : Low Slope Rock
  - (iii) P3 : Steep Natural Vegetation
  - (iv) P4 : Barren Soil
  - (v) P5 : Terraces On Slopes

- Runoff Absorbing Zones – Three Categories
  - (i) A1: Flat and Sandy
  - (ii) A2: Terraces on planes and Wadi beds
  - (iii) A3: Low Slope Vegetation

The SCS curve number method assumes that for any storm rainfall, there will be an initial loss Ia, before any runoff occurs. There will also be an increasing proportional runoff from any subsequent rainfall as the soil water storage capacity is filled, and infiltration capacity decreases, with continuation of rainfall. Thus the volume of runoff Q depends on the volume of rainfall P, and the volume of the storage within the soil available for retention of rainfall. The actual retention during any storm, F, is the difference of volumes of rainfall and runoff. This may be expressed as:

$$F/S = Q/ (P-Ia) \qquad (1)$$

Where S is the potential maximum retention for any soil.

The actual retention when initial abstraction is considered is:

$$F = (P-Ia) – Q \qquad (2)$$

When the two equations above are combined:

$$((P-Ia) - Q) / S = Q / (P – Ia) \qquad (3)$$

$$Q = (P – Ia) \wedge 2 / ((P – Ia) + S) \qquad (4)$$

The initial abstraction is a function of land use, the agriculture practice which affects interception, and also the infiltration, depression and antecedent moisture state of the catchment. An empirical relation ship is proposed by the SCS where *Ia* is estimated from the maximum water storage potential of the soil of the soil by:

$$Ia = 0.2 * S \qquad (5)$$

Substituting the above value of Ia in equation (4)

$$Q = (P – 0.2*s) \wedge 2 / (P + 0.8 S) \qquad (6)$$

Estimation of the soil storage potential for any catchment i.e. the value for S is accomplished through the series of empirical curve numbers, i.e. CN where the storage is:

$$S = ((1000 / CN) – 10)) * 25.4 \qquad (7)$$

CN is an empirical function of all the factors affecting initial losses and runoff volume, including surface physical characteristics of the catchment area, land use, and antecedent rainfall conditions. Each ROC has a CN value, which represents the nature of its response to rainfall. The CN value is estimated using the methods described in the SCS national engineering hand book *(Section 4 Hydrology, Watershed Planning)*.

The model considered the antecedent rainfall on each of the ten preceding days as an indicator of the catchment's moisture condition. The value of the CN of the ROC zones is modified according to the catchment's moisture conditions. This is accomplished by using a multiplying factor, which is based on the value of rainfall in the precedent days, and the value of CN for conditions I and III proposed in the SCS method. The storms are identified with the proper condition out of the three conditions as illustrated in **Table 5.1**.

5.4.3.2 Runoff Volume Estimation for Bahman Project:

Figure 5.2 illustrates the delineation of runoff characteristics zones in the Bahman catchment area. The characteristics of each zone are presented below:

ROC zone	CN1	CN2	CN3	Ks	MC max	Area in Sq. Km
P1	87.2	94	98.1	0.15	40	7.35
P2	75.9	88	95.1	0.2	45	1.76
P3	56.0	75	88.0	0.2	48	0.16
A1	44.0	65	81.7	0.3	60	0.89
Total	**79.7**	**90.1**	**95.96**	**0.17**	**42.74**	**10.16**

The runoff volumes have been computed on the basis of the rainfall record of the Sana'a Airport. Accordingly, the computed runoff, computed with the SCSRRM model, has developed and the values accordingly presented in **Table 5.1** and **Table 5.2**. Both tables are present the estimated values of daily, monthly and annual runoff for the period 1974 t0 1993.

The main general runoff characteristics in the Bahman catchment are summarized as follows:

1. Maximum value of annual runoff: 1,629,089 Cu. M
2. Minimum value of annual runoff: 10,063 Cu. M
3. Average annual runoff: 407,421 Cu. M

5.4.3.3 Inflow Design Flood – Rainfall Simulation

Design flood computations are guided by the data availability. The present conventional method of computing the flood by Unit Hydrograph method requires short interval stream flow data and concurrent precipitation data causing the flood event. Also long term precipitation records and documentation of the storm events which normally occur in the region along with the dew point data record is also required to consider the normal storm transposition techniques. On the basis of the records of rainfall data in Yemen that have been produced by AEC (see table below), the floods for various return periods can be computed.

Extreme Daily Rainfall by Simulation [AEC, 2006]

MAR	R2	R20	R50	R100	R200	R500	R1000	R2000
								est
50	18.6	44.4	55.5	64.7	73.2	84.3	92.8	
75	22.0	48.7	60.4	69.2	78.2	90.0	99.0	
100	24.6	52.0	63.8	73.1	82.6	95.1	104.6	
125	26.9	55.4	67.9	77.7	87.6	100.6	110.5	120
150	28.5	58.4	72.3	83.7	95.4	110.7	122.3	134
175	30.2	59.7	72.1	82.9	93.9	108.3	119.3	129
200	31.3	60.8	73.1	84.2	95.7	111.0	122.6	134
225	32.6	63.5	76.9	88.1	98.7	112.8	123.4	
250	33.7	65.1	78.3	90.1	101.8	117.3	129.0	

Where:

- All values are mm
- MAR is mean annual rainfall
- Rn is the daily rainfall of n-year return period
- R2000 has been estimated by extrapolation from the other values that are derived from long simulations

On the basis of the records of rainfall intensities, the floods for various return periods can be computed.

5.4.4 Inflow Design Flood

5.4.4.1 Unit Hydrograph Approach:

There is no stream flow data available in the Bahman project area. Wherever stream flow observations are not available, estimations and adjustments to the available data are required. The Synthetic Unit-Hydrograph (UH) and Synthetic Storm Hyetograph were used to determine the design flow for catchment area. There are many proposed formula that can be used to evaluate the design flow, e.g. SCS and Snyder's.

For this study, a simple triangular unit hydrograph (UH) was adopted, which is described in more detail in USBR Corps of Engineers "Design of Small Dams" (USBR, 1961). This method uses the Kirpich formula as described below for the time of concentration (Tc).

The Kirpich formula for time of concentration is:

$$Tc = 0.0195 \times L^{0.77} \times S^{-0.385}$$

where Tc = time of concentration in minutes, A = catchment area in km^2, L = length of longest wadi in m, and S = average slope of longest wadi in m/m. However, other standard formulas for Tc may be equally acceptable.

The time to peak (Tp) of the UH is then derived as:

Tp (hours) = 0.6 x Tc + D/2

where D = unit time (some convenient rounded unit of time but not greater than Tp/5), and the total time base (Tb) of the UH is given as 2.67 x Tp. The peak flow (Qp) of the UH is then given as:

Qp (m3/s) = A/ (1.8 x Tb)

where A = catchment area in km^2.

Many other catchment response mechanism models may of course be equally acceptable, but an over-ambitious approach in the face of very limited data seems worth avoiding.

For catchment storm losses, experience in similar areas was drawn on. Various rates were tried, and the final rates adopted were an initial loss of 10 mm followed by a constant rate of 8 mm/hour.

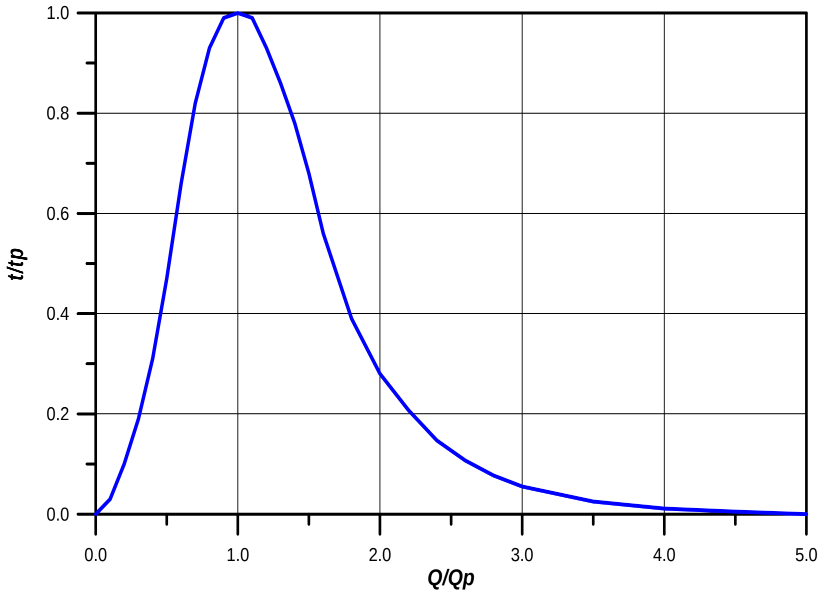
To derive full design flood hydrographs, storm rainfall increments were assembled into design storm profiles. Bell-shaped distributions of design storm rainfall increments are commonly used, putting the most intense increment in the centre and distributing the remaining gradually decreasing increments alternately before and after the centre.

The resulting increments represent a “nested” set of theoretically maximum rainfall increments for each time unit as the duration increases. Such a series of increments is useful for identifying critical durations, but a real storm would not normally be expected to be so “peaked” as to contain such severe increments. For example, a 100-year 12-hour storm would not be expected to contain the 100-year 1-hour rainfall, the 100-year 2-hour rainfall, etc., although it must retain its overall 12-hour total for the 100-year return period. To overcome this problem, a “smoothed” storm profile was adopted by averaging a steady rainfall profile with a peaked rainfall profile.

In order to estimate the inflow hydrograph ordinates, it is necessary to have unit hydrograph which is not available. Therefore, The NRCS synthetic unit hydrograph method was used in the estimation of design flood hydrograph.

In the absence of rainfall and runoff data, synthetic unit hydrograph procedure is used to develop unit hydrographs for the ungauged locations in the watershed or for other watersheds that have similar runoff generation characteristics. Many synthetic unit hydrograph methods have been proposed in the hydrologic literature. One of most the commonly used techniques is the US (National Resources Conservation Service, formerly known as the Soil conservation, SCS) dimensionless unit hydrograph method (SCS, 1985).

The NRCS had analyzed unit hydrographs from a large number of watersheds and derived an average dimensionless unit hydrograph to be used as a standard unit hydrograph for design flood estimation in small ungauged watersheds. The standard NRCS dimensionless unit hydrograph, whose abscissa is the ratio of time (t) to time to peak (tp) i.e. (t/tp); and the ordinate is the ratio of discharge to peak discharge (q/qp) is shown below.



NRCS Dimensionless unit hydrograph (SCS, 1985)

The dimensionless time and runoff ordinates can then be dimensionalized by multiplying the corresponding values (t/tp or Q/Qp) by time from beginning of excess rainfall to the time of peak discharge or the peak runoff Qp respectively.

The computations for inflow design flood hydrograph ordinates are appended at **Table 5.3**.

In applying this method to the various watersheds, the time of concentration was computed for each watershed. The peak discharge values for various return periods have been obtained from the hydrological analysis by rational method for each watershed.

The inflow hydrograph for each watershed corresponding to the peak discharges of various return periods were then obtained by multiplying the ordinates of non dimensionless hydrograph by Qp and the abscissa value by tp.

The inflow hydrograph ordinates computed on the basis of Dimensionless UH approach is appended at **Table 5.3. Figure 5.5** presents the three flood hydrographs for 100-year, 500-year, and 2000-year flood.

5.4.5 Estimation of Bahman Recharge

There are proposals for the construction of 27 check dams, each of 1 to 3 meters height, along the Bahman wadi. The last check dam site intercepts an area of 10.16 sq. km. The length of the wadi is about 4.8 km. The check dams are proposed to be constructed in one phase. The dams will be constructed in the sections of water course where alluvium layers are available with wide stretches and low slopes.

With respect to Bahman, the inflows of the feasibility study computations generally agree with our flows computations for the years 1978 to 1993. Hydrosult have used a different data set of rainfall from 1993 to 1997 (Barasil'a). Considering the proportional similarity in inflow computations for 1978 to 1993, the detailed process of recharge calculations was not gone through. A regression equation was developed for the inflows and natural recharge as also for the inflows and the artificial recharge as computed by Hydrosult and these regression equations were applied to the inflows computed by us for the period 1974 to 1993, and the natural and artificial recharge values have been computed. These are placed at **Table 5.4** and **Table 5.5** for annual and monthly time interval, respectively. The general approach adopted by the Hydrosult is described in the following paragraph.

Estimation of infiltration rate through the wadi bed was done by application of Green and Ampt equation:

$$Q = k * (H + D) / D, \quad m / sec$$

Where
K = the hydraulic conductivity of alluvium layer
D = the depth of runoff water
H = Depth of saturated profile.

The value of the hydraulic conductivity adopted, on the basis of various measurement is stated to be 1.9 * 10 ^ -3. Surface area of the section was obtained from the topographic map. In general the average width adopted by the Hydrosult in their computations was 18 meters which seems to be reasonable. It was assumed that the average flood event is of 4 hour duration. With check dams in position, the stagnation of floods water was considered for3 times the natural duration.

The recharge efficiency was estimated at above both tables with the following main annual inflow and recharge volumes:

	Inflow (m^3)	Recharge (m^3)		Eff. of Check Dams (%)
		Natural	Check Dams	
Average	407,421	156,593	300,005	73
Maximum	1,629,089	483,026	1,097,378	99
Minimum	10,063	9,057	9,560	67

5.4.6 Watershed Monitoring Plan

Recommended monitoring plans for the Bahman Check Dam area are discussed in detail in Section 14. The instrumentation selected for monitoring and collection data is presented in Section 9.

5.5 Future Action for Data Collection

As has been already been brought out in the report, It is very important to create a basic record of data as a primary prerequisite for the future implementation of water resources projects. Basically, following information is required for designing hydrological parameters of a water resources project.

a) Availability of water in the catchment.
b) Design flood for hydraulic structures like dam, barrages, anicuts, weirs, etc.
c) Sediment status of stream.
d) Evaporation Losses as an input for simulation / working table / Reservoir operation etc.

5.5.1 Data Requirement:

For the water availability studies, the following data is required:

1. Rainfall data
2. Stream flow data.

For design flood studies, the following data is required:

1. Short interval stream flow data during the passing of flood wave.
2. Concurrent short interval information of precipitation on recording rain gauge
3. The information of historical storms
4. Extreme event data for use in flood frequency analysis. This can be obtained on the basis of elaborate instrumentation. Peak floods are to be observed during flood season; both the stages as well as the magnitude of the flood.

For determining the reservoir life, sedimentation is an important input. In big reservoir sedimentation is also an input for simulation table, if the life of the reservoir is 1l00 years, then its usual to consider the revised area capacity curves considering sediment status of the reservoir after 50 years after proper sediment distribution studies.

Determination of evaporation values is essential to find out the losses from reservoir by free evaporation from free reservoir surface.

For all the above studies, the following observations are necessary.

- Meteorological data such as Rainfall, temperature, relative humidity, sunshine recorder, wind velocity, evaporation by direct pan evaporimeters.
- Network of hydrometric stations with stage recorders and appropriate instrumentation and methodology.

The inflow to the check dams' site is important for water management. Piezometers are important for recharge measuring through the investigation and recording of the changes in the groundwater level over time. The designed Parshall flume and piezometers are important items for developing a management plan of the runoff through the wadi. This information will be valuable for the planning and design of check dams in similar wadis.

5.5.2 Monitoring Network:

The World Meteorological Organization (WMO) has established comprehensive norms for the establishment of networks of rain gauge stations and hydrometric stations. These norms can be applied to a number of different terrains and climatic zones. Stream gauging manuals, and operational hydrology manuals published by WMO contain comprehensive information on instrumentation and the methodology of observation for specific areas.

The World Bank has taken an active interest in improvement of hydrometeorological networks in some countries. This often has taken the form of a hydrology project for a pilot basin. The Sana'a Basin could consider such an activity for creating a basin-wide monitoring network. Such a network could be applied to surface water and groundwater hydrology projects.

One approach might be the establishment of a network of at least 10 non-recording gauges, supported by an equal number of recording rain gauges and other instrumentation. These instruments could record wind velocity, relative humidity, temperature, and sunshine. This recording would be required to be done on regular, long-term basis until a good data base is created. It is also necessary to create an infrastructure for establishing such a network that could use electronic systems and computers for recording, analyzing, storage and retrieval of data.

Stream flow measurement facilities, with water stage recorders and current meter measurements, should also be considered as a method of monitoring the flows in big and small wadis. In very small streams such the project catchments for the six dams under study, small flumes can be established for measurement of seasonal flows. To be effective, these activities should be initiated at least on 10 to 12 wadis, each with a catchment are of 50-100 km^2.

5.6 Sedimentation and Wadi Rehabilitation

The situation at Wadi Bahman is slightly different, as the check dams do not act to retain water in the same manner or scale as a large gravity dam. Water will not accumulate in the wadi for long periods of time, and any recharge (or sedimentation issues) will be localized at the areas directly upstream of a check dam. The sedimentations will actually rehabilitate the wadi, as sediments will be initially trapped by the check dams.

The construction of each check dam will consist of stones of varying size; by the very nature of the construction (see Section 9), the dams will be porous and have a number of voids. Suspended sediments will wash through the check dams during the first year, with the result the sedimentations will penetrate and reduce the permeability of each check dam.

As more sediment builds up within each dam, the ponding capability of the uppermost check dams in the wadi will be enhanced. This will increase the recharge, possibly as soon as within one rainy season after completion of construction. The sediment accumulation upstream within the series of check dams will reduce the wadi bed slope, which will in turn reduce the inflow stream velocity, and the susceptibility of the wadi banks to erosion will decrease.

Wadi Bahman suffers from an erosion problem. Local farmers have noted that erosion protection is required, as the wadi banks are subjected to wind and water erosion. Flood events accelerate this process. While the farmers readily admit some erosion protection measures are needed, it is possible that the traditional Yemeni terrace building might be adapted to the wadi banks as a method of soil retention, and protection of vulnerable areas against high flood waters.

ANNEX A Dam and Data Monitoring and Recording

One of the greatest challenges in Yemen, and the Sana'a Basin, with regards to hydrology is the availability and reliability of data. A number of key sources of data that are normally used in hydrological calculations were either unavailable or not considered reliable due to inconsistencies in the data sets. As the new dams and rehabilitated dams are commissioned and new instrumentation packages are installed, it is important that proper procedures for data collection, monitoring, and storage are utilized.

This section contains some general observations on the importance of monitoring. Detailed discussion of monitoring the performance of each dam has been included in Section 14, as well as within a separately bound Monitoring Plan. Instrumentation that has been proposed as part of the design to monitor the performance of each dam has been identified and discussed in Section 9.

Additional information regarding the operation and maintenance of each dam is also given in Section 14, as well as in the separately bound Plan Report.

A.1 Instrumentation

Several different types of instruments can be used to accurately record and collect hydrologic and hydraulic data. The following useful data sets are identified below as a sample of information that will be useful in generating a comprehensive picture of the hydrologic conditions within the Sana'a Basin. Instrumentation that may be useful in the collection of this data is also suggested.

- Rainfall. Rainmeter gauges and climatological stations can record this information.
- Stream Flow during Flood Events. Flowmeters located within Venturi-type flumes, such as Parshall flumes, can assist with the recording of this information.
- Groundwater Levels. This information can be recorded through the use of piezometers or observation wells.
- Climatological Data. Temperature, humidity, wind speed and direction, and rainfall – this information can be accurately recorded through the use of climatological stations. The National Water Resource Authority (NWRA) has responsibility for the deployment and operation of these stations. NWRA should be consulted and involved in the coordination of a comprehensive data gathering program within the Sana'a Basin.

A.2 Data Collection

Data must be accurately recorded. A standard, internationally acceptable procedure (such as those developed by the World Meteorological Organization, WMO) should be utilized by all data recorders whenever possible. If a procedure must be generated by NWRA or GDI, this procedure should be standardized and communicated to all individuals responsible for data collection.

As the data is collected, it should be transmitted to a central collection source on regular basis. If data is not centrally recorded, the potential for the loss of significant quantities of data increases every day. It does not appear that a standardized procedure currently exists within SBMWP for obtaining, recording and storing this data in a single location.

One of the greatest challenges of data collection is that each recorder should utilize a regular, standardized procedure. Data collection is a de-centralized activity; in order for accurate rainfall information to be recorded on a daily basis, someone must be physically present to review the performance of the instrument, record the data, and store it. At regular intervals, this data should be transferred to a central location for processing and storage.

A.3 Data Recordkeeping and Storage

As part of the ongoing project, the PCU should cooperate with GDI and NWRA to identify a central source of recordkeeping information for the basin. There are a number of ministries that have responsibility for different types of information. For example, the Ministry of Civil Aviation and Meteorology is responsible for some types of meteorological and climatological information, whereas the Ministry of Water and Environment maintains responsibility for the water resources data. An agency that is within the Ministry of Water and Environment is the most logical resource for centralizing and storing this data.

It is suggested that only raw data be collected from the individuals who are responsible for field data records. This allows the data collectors to focus specifically on the task of identifying and collecting information. A nominated expert can collect this information at a central location, process it for accuracy and correctness, and prepare it for long-term storage.
Data storage is as important as the collection process. While the exact procedures to be followed should be developed internally, a number of recommendations can be offered.

1. Data should be stored in both hard copy and electronic formats. Electronic data sets should be transferred into a widely-available medium that can be updated as new

versions are released, such as Microsoft Word or Excel. Electronic data that remains in a raw format may deteriorate over time, or computers may advance to the point where the raw data can no longer be read or accessed.

2. Electronic data should be stored on a central server in order to prevent against the loss of the data if it is stored on a local computer hard drive.
3. Specific individuals should be authorized to access, update, and review the electronic data. The official files should be password-protected to prevent against accidental data manipulation or loss.
4. The electronic data should be reviewed and updated on a regular basis.
5. Other protective measures should be implemented as determined by the PCU, GDI, NWRA, or other responsible agency. Ideally, these procedures should be complementary to existing data protection activities.

A.4 Recommendations - Training

As part of any O&M training that is given to the inhabitants of a given dam area, it is recommended that responsible individuals be nominated to assist (or be fully responsible) with the evaluation of instruments, recording of information, and temporary storage of data before it is transmitted to a central agency in Sana'a. This training will most likely require hands-on instruction, both in the classroom and in the field. Training in data collection should be an ongoing process, and refresher training on an annual basis is recommended.

Short refresher training courses provide several benefits:

1. Data collectors are reminded of the full procedures they must follow.
2. An opportunity exists for data collectors to discuss problems and challenges with data collection.
3. Working relationships between the central collection agency (PCU or GDI) and the field staff are strengthened.

Should a field data collector need to be replaced for any reason, a new data collector should be trained immediately. This training should be given in the same manner as initial training for the data collectors; the previous data collector can be involved, but he or she should not train the new data collector. The formal training procedure will remind the new data collector of the serious need to collect data regularly and accurately, and it will give the responsible manager in Sana'a the opportunity to interact with the field data collector.

In the initial stages of this new data collection activity, the SBWMP may elect to make a consultant responsible for the training activity. This may provide both field and office staff with an opportunity to learn about the most recent techniques and considerations in data collections. It will certainly result in a standardized procedure. One part of the training should be a "train-the-trainer" approach for staff in Sana'a. This will ensure that multiple individuals within the Yemeni government are not only properly trained in data collection and storage procedures, but they can also impart this knowledge to other individuals in the future.

A.5 Recommendations – Quality Control / Assurance

An external consultant could also be utilized as an additional resource for providing quality control and quality assurance of field data collection, data processing, and data storage. This activity should be provided to the SBWMP over a period of at least six months to a year. As time passes, the quality control responsibilities should be gradually turned over to responsible members of the PCU, GDI, or NWRA. These individuals should have responsibility for the long term quality assurance and review of data collected from the dam sites within the Sana'a Basin. It is highly recommended that the individuals responsible for quality control are not the same individuals responsible for data processing and storage.

Recommended quality control activities include the following:

- Assistance in developing procedures for data collection and storage.
- Assistance in writing manuals for data collection and storage procedures.
- Review of field collectors' data collection procedure and activity.
- Observation of field data collection.
- Observation of field evaluation of instrumentation.
- Review of centralized data collection procedures.
- Review of data, after it has been processed for storage.
- Review of data storage activities and procedures.
- Review of training activities.
- Observation of training activities – especially "train the trainer" courses.

A.6 Recommendations – Funding

The greatest challenge to all of these issues, from record keeping to quality assurance, is funding. People will need to be convinced of the value of these activities, especially if they will not experience direct benefit from them.

WUAs and public awareness programs will prove very helpful in convincing communities of the need to support field activities – data collection; small-scale desiltation; operation and maintenance of the dams; and other related activities. In communities where strong, collaborative activities and approaches to agriculture exist, it will be easier to generate public support for volunteer activity. Community leaders and influential members should be approached early in the process, as their backing for these programs will be vital.

Some communities already have community-owned wells, where each owner is responsible for the upkeep and operation of the well based upon his anticipated benefit through pumped water. A similar system of community upkeep and funding may be applied to the dam. A fund could be collected and maintained by the WUA for proper O&M activities, dam repair, and general upkeep. Dam operators and observers could also be paid out of this fund.

Each farmer might contribute to the fund based upon his landholdings. Alternately, all members of the community could contribute equally to this dam O&M fund. If the costs of establishing and maintaining this fund are prohibitive, it may be possible to create an in-kind system, where the government of Yemen provides funding equal to the monies generated by the WUA for dam maintenance.

Figures

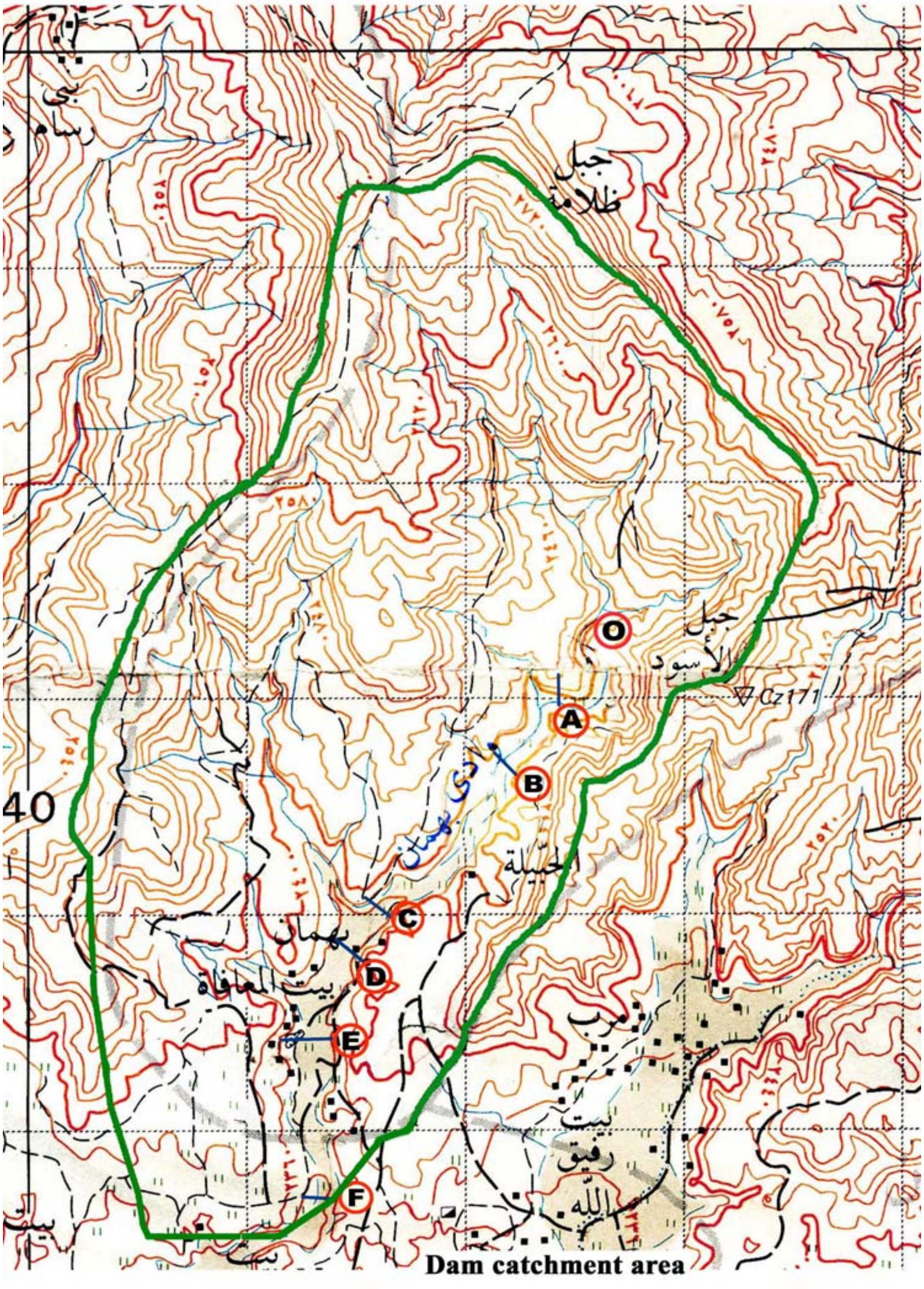


Figure 5.1. Dam Catchment Area Map (scale 1:25000) (Hydrosult, 2002)

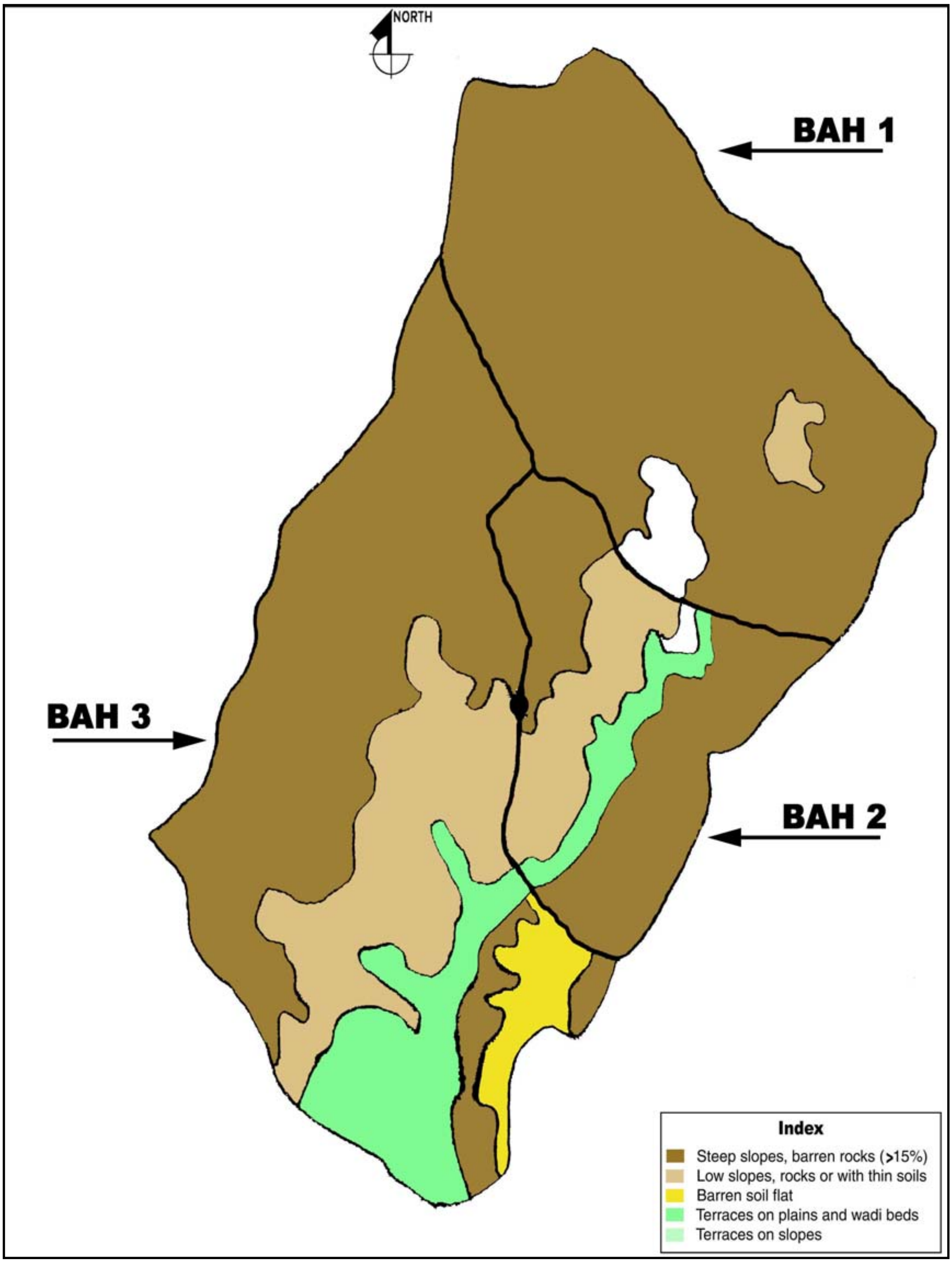


Figure 5.2. Delineation Curves. (Hydrosult, 2002)

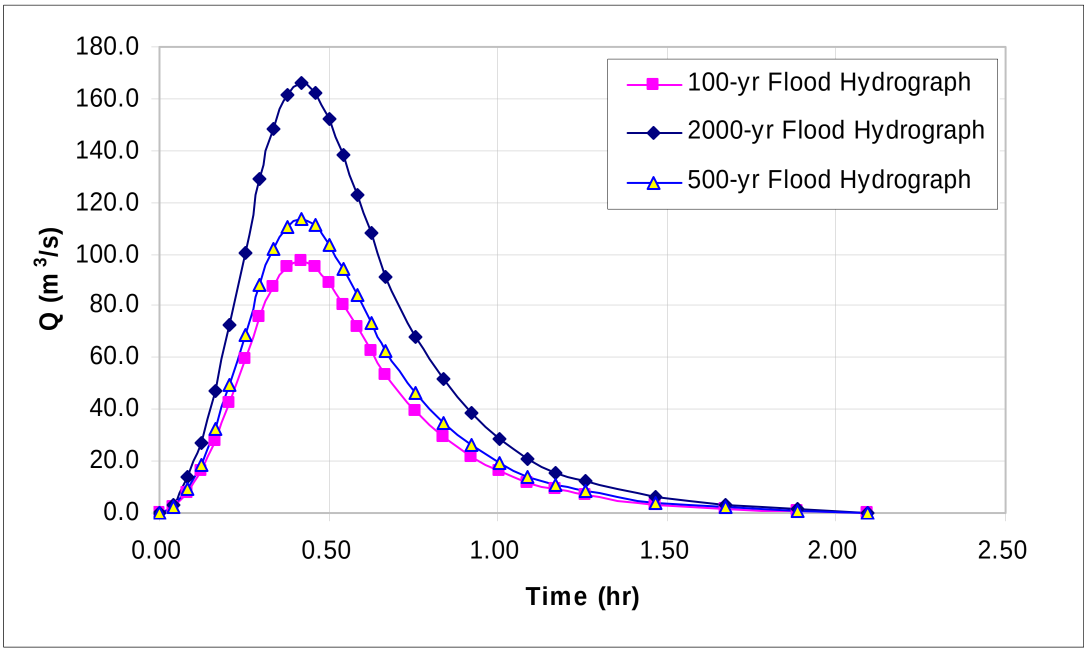


Figure 5.3. Flood Hydrographs for 100-Year, 500-Year, and 2000-Year.

Table 5.1: Storm by Storm Runoff Estimation.

Year	Date of Storm	Hydrological Type	Precipitation (mm)	Runoff (mm)	Volume (m^3)
1974	3-4/4	I	23.8	2.46	25025
	9/4	II	14.2	2.65	26909
	11 04 74	II	9	0.69	6960
	10 05 74	I	15.2	0.00	0
	13 05 74	II	52	30.54	310306
	23-25 05 74	I	26.6	3.45	35052
	6-7.8.74	I	22.4	2.02	20533
	09 08 74	II	9	0.69	6960
	15 08 74	I	6	0.00	0
	Total Yearly		**178.20**	**42.49**	**431744**
	Annual Runoff Coefficient			**0.24**	**0**
					0
1975	09 03 75	I	20.00	1.35	13715
	12 03 75	II	17.10	4.11	41806
	21 03 75	I	7.00	0	0
	28 03 75	I	20.00	1.35	13715
	30/3-3/4 75	II	56.00	34.05	345983
	06 04 75	III	12.00	5.42	55111
	09 04 75	III	5.00	0.90	9140
	19 04 75	I	3.40	0	0
	25 04 75	I	39.00	9.17	93123
	27-30 07 75	I	84.50	40.56	412094
	08. 08 75	I	10.10	0	0
	11 08 75	I	10.00	0	0
	12 08 75	I	4.00	0	0
	16-17 08 75	I	14.90	0	0
	22-23 08 75	I	37.30	8.27	84043
	27 08 75	III	7.00	1.96	19884
	Total Yearly		**347.30**	**107.15**	**1088614**
	Annual Runoff Coefficient			**0.31**	**0**
1976	04 03 76	I	12.00	0	0
	28 03 76	I	9.70	0	0
	10 04 76	I	7.00	0	0
	15 04 76	I	5.40	0	0
	24 04 76	I	7.00	0	0
	28-29 04 76	I	9.60	0	0
	06 05 76	I	7.90	0	0

Year	Date of Storm	Hydrological Type	Precipitation (mm)	Runoff (mm)	Volume (m^3)
	12-13 05 76	I	10.50	0	0
	23 07 76	I	14.50	0	0
	04-05 11 76	I	32.50	5.92	60190
	Total Yearly		**116.10**	**5.92**	**60190**
	Annual Runoff Coefficient			**0.051**	**0**
					0
1977	19 01 77	I	10.4	0	0
	12 03 77	I	8.9	0	0
	29 03 77	I	18.4	0	0
	29 04 77	I	6.6	0	0
	21-26 05 77	I	67.4	27.50	279381
	01 08 77	I	19	1.105	11226
	13 08 77	I	5.4	0.00	0
	14-17 08 77	I	74.4	32.71	332364
	19 08 77	III	5.1	0.95	9608
	24-30 10 77	I	111.4	62.82	638269
	Total Yearly		**327.00**	**125.08**	**1270847**
	Annual Runoff Coefficient			**0.383**	**0**
					0
1978	24 02 78	I	4.7	0.00	0
	02 03 78	I	10.4	0.00	0
	01 05 78	I	19	0.00	0
	06 05 78	II	7	0.00	0
	11-12 07 78	I	30.8	5.16	52437
	16-17 07 78	III	13.5	6.60	67089
	19 07 78	II	5	0.00	0
	23-24 07 78	I	23.7	2.43	24692
	31 07 78	II	6	0.00	0
	12 08 78	I	4.9	0.00	0
	22 08 78	I	10.5	0.00	0
	15 11 78	I	5.4	0.00	0
	Total Yearly		**140.90**	**14.19**	**144218**
	Annual Runoff Coefficient			**0.101**	**0**
					0
1979	01 01 79	I	3.5	0.00	0
	12 01 79	I	3.6	0.00	0
	27 01 79	I	4.2	0.00	0
	13 03 79	I	6.5	0.00	0
	17 03 79	I	3.9	0.00	0

Year	Date of Storm	Hydrological Type	Precipitation (mm)	Runoff (mm)	Volume (m^3)
	29 03 79	I	15	0.00	0
	06 05 79	I	6.5	0.00	0
	08 05 79	I	6.5	0.00	0
	17 07 79	I	4.5	0.00	0
	15 08 79	I	9.7	0.00	0
	22 08 79	I	4.8	0.00	0
	Total Yearly		**68.70**	**0.00**	**0**
	Annual Runoff Coefficient			**0.000**	**0**
					0
1980	27 02 80	I	12	0.00	0
	26-28 03 80	I	34.8	7.02	71275
	17-19 04 80	I	41.2	10.37	105318
	12 08 80	I	4	0.00	0
	14 08 80	I	8.7	0.00	0
	17 10 80	I	36.9	8.07	81952
	23 10 80	I	4	0.00	0
	Total Yearly		**141.60**	**25.45**	**258545**
	Annual Runoff Coefficient			**0.180**	**0**
					0
1981	15 03 81	I	10	0.00	0
	19-20 03 81	I	20	0.00	0
	28-30 03 81	I	30.6	5.07	51550
	07 06 81	I	20	1.35	13715
	02 08 81	I	29.5	4.60	46777
	06 08 81	III	4.8	0.00	0
	15 08 81	I	5	0.00	0
	17 08 81	I	7.7	0.00	0
	20 08 81	I	25	2.87	29158
	Total Yearly		**152.60**	**13.90**	**141200**
	Annual Runoff Coefficient			**0.091**	**0**
					0
1982	12 01 82	I	5.6	0.00	0
	07 02 82	I	8.4	0.00	0
	11 02 82	I	3.5	0.00	0
	12 02 82	I	7	0.00	0
	04 03 82	I	14.6	0.00	0
	30-31 03 82	II	28.9	11.76	119450
	03 04 82	III	19.8	0.00	0
	12 04 82	I	13.5	0.00	0

Year	Date of Storm	Hydrological Type	Precipitation (mm)	Runoff (mm)	Volume (m^3)
	09 05 82	II	89.8	65.12	661598
	09 08 82	I	12	0.00	0
	11 10 82	I	6.9	0.18	1838
	13 10 82	I	32.2	5.79	58794
	15 10 82	III	11	4.67	47411
	Total Yearly		**253.20**	**87.51**	**889091**
	Annual Runoff Coefficient			**0.346**	**0**
					0
1983	30-31 01 83	I	33.4	6.34	64448
	03 02 83	III	3.9	0.45	4598
	11 02 83	I	6.3	0	0
	09 03 83	I	32	5.70	57870
	13-14 03 83	III	77	66.90	679722
	20 03 83	I	7.7	0	0
	29 03 83	I	9.9	0	0
	07 04 83	I	6.1	0	0
	24-28 04 83	I	76.7	34.47	350204
	25 05 83	I	4.6	0	0
	14-17 08 83	I	55.9	46.16	468986
	22 08 83	III	3.5	0.32	3261
	Total Yearly		**317.00**	**160.34**	**1629089**
	Annual Runoff Coefficient			**0.506**	**0**
					0
1984	19 03 84	I	5.1	0.00	0
	12 04 84	I	4.3	0.00	0
	09-15 05 84	I	84.9	40.88	415322
	27 05 84	I	11	0.00	0
	14 08 84	I	7.6	0.00	0
	12-13 12 84	I	14.6	0.30	3021
	Total Yearly		**127.50**	**41.18**	**418343**
	Annual Runoff Coefficient			**0.323**	**0**
					0
1985	05 04 85	I	4	0	0
	10-11 04 85	I	13.1	0	0
	13 04 85	II	13	2.11	21445
	22 04 85	I	47.7	14.17	143974
	28-30 04 85	I	28.7	4.27	43415
	05 05 85	III	10	3.94	39984
	09-10 05 85	I	14.7	0	0

Year	Date of Storm	Hydrological Type	Precipitation (mm)	Runoff (mm)	Volume (m^3)
	12 05 85	I	6.4	0	0
	20 07 85	I	9.6	0	0
	Total Yearly		**147.20**	**24.49**	**248817**
	Annual Runoff Coefficient			**0.166**	**0**
					0
1986	04-05 03 86	I	41.2	10.37	105318
	08 03 86	III	41.2	31.89	324014
	10 03 86	III	8.2	2.70	27463
	22 03 86	I	4.6	0	0
	24 03 86	I	13.9	0	0
	06 04 86	I	11.7	0	0
	11-12 04 86	I	14	0	0
	15 04 86	I	5.1	0	0
	17 04 86	I	8.4	0	0
	22-23 04 86	I	21	1.62	16415
	26 04 86	II	7.6	0	0
	22 06 86	I	23	2.21	22413
	28-29 07 86	I	19.2	1.15	11706
	02 08 86	II	5.8	0	0
	17-18.08.86	I	27.4	3.76	38157
	Total Yearly		**252.30**	**53.69**	**545487**
	Annual Runoff Coefficient			**0.213**	**0**
					0
1987	07 03 87	I	5.0	0	0
	10 04 87	I	5.7	0	0
	10 05 87	I	3.7	0	0
	23 05 87	I	9.0	0	0
	13 06 87	I	18.5	0.9905	10063
	07 08 87	I	5.2	0	0
	11-12 08 87	I	10.5	0	0
	08 09 87	I	18.2	0.0	0
	Total Yearly		**75.80**	**0.99**	**10063**
	Annual Runoff Coefficient			**0.013**	**0**
					0
					0
1988	20-21 02 88	I	22.2	1.96	19921
	26-27 02 88	II	15.2	3.13	31791
	15 04 88	I	19	1.105	11226
	17-18 04 88	I	22.4	2.02	20533

Year	Date of Storm	Hydrological Type	Precipitation (mm)	Runoff (mm)	Volume (m^3)
	20 04 88	III	6	1.39	14171
	22 04 88	III	6.3	1.56	15819
	24 04 88	II	8.7	0.60	6146
	16 07 88	I	6	0	0
	19 07 88	I	8.7	0	0
	21 07 88	I	32	5.70	57870
	26 07 88	III	11.6	5.12	52001
	30 07 88	I	7.3	0	0
	17 08 88	I	3.7	0	0
	01 09 88	I	7.8	0	0
	Total Yearly		**176.90**	**22.59**	**229477**
	Annual Runoff Coefficient			**0.128**	**0**
					0
1989	03 04 89	I	8.9	0	0
	07-10 04 89	I	42.5	11.10	112747
	25-27 04 89	I	21.7	1.81	18425
	09 06 89	I	8.5	0	0
	23 07 89	I	5.5	0	0
	19 08 89	I	3.5	0	0
	29 08 89	I	3.8	0	0
	19 12 89	I	4.3	0	0
	Total Yearly		**98.70**	**12.91**	**131173**
	Annual Runoff Coefficient			**0.131**	**0**
					0
1990	05 02 90	I	7.8	0	0
	08 02 90	I	13.5	0	0
	03 03 90	I	4.2	0	0
	24 03 90	I	7	0	0
	28-29 03 90	I	15.5	0	0
	03 04 90	II	12.7	1.98	20151
	24-25 04 90	I	13.5	0	0
	01 06 90	I	4	0	0
	24 07 90	I	4.6	0	0
	26-27 07 90	I	19	1.10	11226
	31 07-01 08 90	II	8.6	0.579	5884
	18 08 90	I	4.3	0	0
	Total Yearly		**114.70**	**3.67**	**37261**
	Annual Runoff Coefficient			**0.032**	**0**
					0

Year	Date of Storm	Hydrological Type	Precipitation (mm)	Runoff (mm)	Volume (m^3)
1991	15 02 91	I	4	0	0
	09 03 91	I	6.8	0	0
	17 03 91	I	10	0	0
	30 03-01 04 91	I	12.1	0	0
	07 05 91	I	4.2	0	0
	07 06 91	I	7.5	0	0
	14 08 91	I	7.3	0	0
	Total Yearly		**51.90**	**0.00**	**0**
	Annual Runoff Coefficient			**0.000**	**0**
					0
1992	22 03 92	I	3.8	0	0
	24 03 92	I	15	0	0
	01 04 92	I	6.2	0	0
	27 04 92	I	10	0	0
	08 05 92	I	3.7	0	0
	29 07 92	I	15.8	0	0
	01 08 92	II	13.6	2.37	24120
	11-15 08 92	I	55.2	18.97	192713
	18 08 92	III	4	0.49	4961
	23 08 92	I	21.4	1.73	17552
	10 10 92	I	24.7	2.77	28101
	Total Yearly		**173.40**	**26.32**	**267448**
	Annual Runoff Coefficient			**0.152**	**0**
					0
1993	01 04 93	I	8	0	0
	07-09 04 93	I	35.6	7.41	75282
	15-17 04 93	I	27	3.60	36592
	19 04 93	III	4.5	0.68	6931
	28 04 93	I	4.4	0	0
	05. 05 93	I	4.4	0	0
	07 05 93	I	12.8	0	0
	13-15 05 93	I	56.6	19.90	202232
	17 05 93	III	4.8	0.81	8229
	09-10 08 93	I	21.4	1.73	17552
	Total Yearly		**179.50**	**34.14**	**346818**
	Annual Runoff Coefficient			**0.190**	

Table 5.2: Monthly Runoff and Runoff Coefficient

Year	Month	Runoff (m^3)	Monthly Runoff Coefficient
1974	Apr 1974	58893	0.12
	May 1974	345359	0.36
	July 1974	20533	0.09
	August 1974	6960	0.05
1975	Mar 1975	415219	0.34
	Apr 1975	157373	0.26
	July 1975	412094	0.48
	August 1975	103927	0.12
1976	Mar. 1976	0	0.00
	Apr. 1976	0	0.00
	May. 1976	0	0.00
	July 1976	0	0.00
	Nov 1976	60190	0.18
1977	Jan. 1977	0	0.00
	Mar 1977	0	0.00
	Apr. 1977	0	0.00
	May 1977	279381	0.41
	Aug. 1977	353197	0.33
	Oct 1977	638269	0.56
1978	Feb. 1978	0	0.00
	Mar. 1978	0	0.00
	May. 1978	0	0.00
	July 1978	144218	0.18
	Aug 1978	0	0.00
	Nov 1978	0	0.00
1979	Jan. 1979	0	0.00
	Mar. 1979	0	0.00
	May. 1979	0	0.00
	July 1979	0	0.00
	Aug. 1979	0	0.00
1980	Feb 1980	0	0.00
	Mar 1980	71275	0.20
	Apr 1980	105318	0.25
	Aug 1980	0	0.00
	Oct 1980	81952	0.20
1981	Mar 1981	51550	0.08
	June 1981	13715	0.07
	Aug 1981	75934	0.10

Year	Month	Runoff (m^3)	Monthly Runoff Coefficient
1982	Jan. 1982	0	0.00
	Feb 1982	0	0.00
	Mar 1982	119450	0.27
	Apr 1982	0	0.00
	May 1982	661598	0.73
	Aug 1982	0	0.00
	Oct 1982	108043	0.21
1983	Jan 1983	64448	0.19
	Feb 1983	4598	0.04
	Mar 1983	737592	0.57
	Apr 1983	350204	0.42
	May 1983	0	0.00
	Aug 1983	472247	0.78
1984	Mar. 1984	0	0.00
	Apr 1984	0	0.00
	May 1984	415322	0.43
	Aug 1984	0	0.00
	Dec 1984	3021	0.02
1985	Apr 1985	208834	0.19
	May 1985	39984	0.13
	July 1985	0	0.00
1986	Mar 1986	456796	0.41
	Apr 1986	16415	0.02
	June 1986	22413	0.10
	July 1987	11706	0.06
	Aug 1987	38157	0.11
1987	Mar 1987	0	0.00
	Apr 1987	0	0.00
	May 1987	0	0.00
	June 1987	10063	0.05
	Aug 1987	0	0.00
	Sept 1987	0	0.00
1988	Feb 1988	51712	0.14
	Apr 1988	67895	0.11
	July 1988	109870	0.16
	Aug 1988	0	0.00
	Sept 1988	0	0.00

Year	Month	Runoff (m^3)	Monthly Runoff Coefficient
1989	Apr 1989	131173	0.18
	June 1989	0	0.00
	July 1989	0	0.00
	Aug 1989	0	0.00
	Dec 1989	0	0.00
1990	Feb 1990	0	0.00
	Mar 1990	0	0.00
	Apr 1990	20151	0.08
	June 1990	0	0.00
	July 1990	11226	0.05
	Aug 1990	5884	0.04
1991	Feb 1991	0	0.00
	Mar 1991	0	0.00
	Apr 1991	0	0.00
	May 1991	0	0.00
	June 1991	0	0.00
	Aug 1991	0	0.00
1992	Mar 1992	0	0.00
	Apr 1992	0	0.00
	May 1992	0	0.00
	July 1992	0	0.00
	Aug1992	239347	0.25
	Oct 1992	28101	0.11
1993	Apr. 1993	118805	0.15
	May 1993	210462	0.26
	Aug. 1993	17552	0.08

Table 5.3: Flood Hydrographs Calculations for 100-Year, 500-Year and 2000-Year

Wadi Name	Length L(km)	Area (Km^2)	Slope (%)	tc min	tp min	Tbase min	Qp m^3/s
Bahman	**4.80**	**10.16**	**6.70**	**37.72**	**25.13**	**67.10**	**5.05**

Initial Abstractions	10						
Rate of Abstractions	8	C.Ct=	0.6				
	Tp (h) =	0.42	Qp (m^3/s) =	5.05	**Flood Flow (m^3/s)**		
	T/Tp	**T(hr)**	**Q/QP**	**Q(m^3/s)**	**100-Year**	**500-Year**	**2000-Year**
	0	0.00	0	0.0	0	0	0
	0.1	0.04	0.02	0.1	2.0	2.3	3.4
	0.2	0.08	0.08	0.4	8.1	9.3	13.6
	0.3	0.13	0.16	0.8	16.1	18.6	27.1
	0.4	0.17	0.28	1.4	28.0	32.5	47.3
	0.5	0.21	0.43	2.2	42.8	49.7	72.4
	0.6	0.25	0.6	3.0	59.5	69.1	100.7
	0.7	0.29	0.77	3.9	76.0	88.4	128.9
	0.8	0.34	0.89	4.5	87.4	101.8	148.6
	0.9	0.38	0.97	4.9	94.8	110.6	161.5
	1	0.42	1	5.0	97.3	113.6	166.0
	1.1	0.46	0.98	4.9	94.9	111.0	162.2
	1.2	0.50	0.92	4.6	88.7	103.8	151.8
	1.3	0.54	0.84	4.2	80.6	94.5	138.3
	1.4	0.59	0.75	3.8	71.6	84.0	123.1
	1.5	0.63	0.66	3.3	62.7	73.7	108.0
	1.6	0.67	0.56	2.8	52.9	62.3	91.4
	1.8	0.75	0.42	2.1	39.3	46.4	68.2
	2	0.84	0.32	1.6	29.7	35.1	51.6
	2.2	0.92	0.24	1.2	22.0	26.1	38.5
	2.4	1.01	0.18	0.9	16.3	19.5	28.7
	2.6	1.09	0.13	0.7	11.7	14.0	20.6
	2.8	1.17	0.1	0.5	8.9	10.7	15.8
	3	1.26	0.08	0.4	7.0	8.5	12.5
	3.5	1.47	0.04	0.2	3.4	4.2	6.2
	4	1.68	0.02	0.1	1.7	2.0	3.0
	4.5	1.88	0.01	0.1	0.8	1.0	1.5
	5	2.09	0	0.0	0	0	0

Table 5.4: Monthly Recharge, Natural and with Check Dams

Year	Month	Runoff (m^3)	Natural Recharge (Without Check Dams)	Recharge With Check Dams	Recharge Efficiency
1974	Apr 1974	58893	43802	55642	0.94
	May 1974	345359	157364	272476	0.79
	July 1974	20533	20447	21598	1.05
	August 1974	6960	9353	8174	1.17
1975	Mar 1975	415219	179783	321502	0.77
	Apr 1975	157373	89149	134515	0.85
	July 1975	412094	178804	319328	0.77
	August 1975	103927	66043	92669	0.89
1976	Mar. 1976	0	0	0	
	Apr. 1976	0	0	0	
	May. 1976	0	0	0	
	July 1976	0	0	0	
	Nov 1976	60190	44497	56741	0.94
1977	Jan. 1977	0	0	0	
	Mar 1977	0	0	0	
	Apr. 1977	0	0	0	
	May 1977	279381	135000	225236	0.81
	Aug. 1977	353197	159938	278024	0.79
	Oct 1977	638269	245331	473023	0.74
1978	Feb. 1978	0	0	0	
	Mar. 1978	0	0	0	
	May. 1978	0	0	0	
	July 1978	144218	83696	124372	0.86
	Aug 1978	0	0	0	
	Nov 1978	0	0	0	
1979	Jan. 1979	0	0	0	
	Mar. 1979	0	0	0	
	May. 1979	0	0	0	
	July 1979	0	0	0	
	Aug. 1979	0	0	0	
1980	Feb 1980	0	0	0	
	Mar 1980	71275	50281	66043	0.93
	Apr 1980	105318	66681	93782	0.89
	Aug 1980	0	0	0	
	Oct 1980	81952	55621	74865	0.91
1981	Mar 1981	51550	39781	49370	0.96
	June 1981	13715	15273	15032	1.10
	Aug 1981	75934	52637	69909	0.92

Year	Month	Runoff (m^3)	Natural Recharge (Without Check Dams)	Recharge With Check Dams	Recharge Efficiency
1982	Jan. 1982	0	0	0	
	Feb 1982	0	0	0	
	Mar 1982	119450	73037	105010	0.88
	Apr 1982	0	0	0	
	May 1982	661598	251782	488522	0.74
	Aug 1982	0	0	0	
	Oct 1982	108043	67924	95958	0.89
1983	Jan 1983	64448	46751	60334	0.94
	Feb 1983	4598	6931	5634	1.23
	Mar 1983	737592	272374	538634	0.73
	Apr 1983	350204	158957	275907	0.79
	May 1983	0	0	0	
	Aug 1983	472247	197315	360894	0.76
1984	Mar. 1984	0	0	0	
	Apr 1984	0	0	0	
	May 1984	415322	179815	321573	0.77
	Aug 1984	0	0	0	
	Dec 1984	3021	5116	3863	1.28
1985	Apr 1985	208834	109383	173429	0.83
	May 1985	39984	33105	39297	0.98
	July 1985	0	0	0	
1986	Mar 1986	456796	192625	350272	0.77
	Apr 1986	16415	17392	17665	1.08
	June 1986	22413	21785	23367	1.04
	July 1987	11706	13621	13040	1.11
	Aug 1987	38157	32005	37681	0.99
1987	Mar 1987	0	0	0	
	Apr 1987	0	0	0	
	May 1987	0	0	0	
	June 1987	10063	12210	11383	1.13
	Aug 1987	0	0	0	
	Sept 1987	0	0	0	
1988	Feb 1988	51712	39871	49509	0.96
	Apr 1988	67895	48546	63224	0.93
	July 1988	109870	68753	97414	0.89
	Aug 1988	0	0	0	
	Sept 1988	0	0	0	

Year	Month	Runoff (m^3)	Natural Recharge (Without Check Dams)	Recharge With Check Dams	Recharge Efficiency
1989	Apr 1989	131173	78151	114220	0.87
	June 1989	0	0	0	
	July 1989	0	0	0	
	Aug 1989	0	0	0	
	Dec 1989	0	0	0	
1990	Feb 1990	0	0	0	
	Mar 1990	0	0	0	
	Apr 1990	20151	20171	21237	1.05
	June 1990	0	0	0	
	July 1990	11226	13214	12558	1.12
	Aug 1990	5884	8284	7030	1.19
1991	Feb 1991	0	0	0	
	Mar 1991	0	0	0	
	Apr 1991	0	0	0	
	May 1991	0	0	0	
	June 1991	0	0	0	
	Aug 1991	0	0	0	
1992	Mar 1992	0	0	0	
	Apr 1992	0	0	0	
	May 1992	0	0	0	
	July 1992	0	0	0	
	Aug1992	239347	120718	196026	0.82
	Oct 1992	28101	25654	28629	1.02
1993	Apr. 1993	118805	72751	104500	0.88
	May 1993	210462	109999	174643	0.83
	Aug. 1993	17552	18255	18760	1.07

Table 5.5: Annual Recharge, Natural and with Check Dams

Year	Runoff (m^3)	Runoff Coeff.	Natural Recharge (Without Check Dams)	Recharge With Check Dams
1974	431744	0.24	184928	332970
1975	1088614	0.31	360906	764055
1976	60190	0.051	44497	56741
1977	1270847	0.383	403640	878000
1978	144218	0.101	83696	124372
1979	0	0.000	0	0
1980	258545	0.180	127643	210091
1981	141200	0.091	82426	122032
1982	889091	0.346	311762	637026
1983	1629089	0.506	483026	1097378
1984	418343	0.323	180760	323673
1985	248817	0.166	124153	202978
1986	545487	0.213	218993	410785
1987	10063	0.013	9057	9560
1988	229477	0.128	117098	188750
1989	131173	0.131	78151	114220
1990	37261	0.032	31459	36885
1991	0	0.000	0	0
1992	267448	0.152	130806	216577
1993	346818	0.190	157844	273511

SECTION SIX: GEOTECHNICAL INVESTIGATIONS AND FINDINGS

No additional geotechnical investigations were carried out at the Bahman site.

SECTION SEVEN: HYDROGEOLOGICAL EVALUATION OF BAHMAN CHECK DAMS SITE

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SECTION SEVEN: HYDROGEOLOGICAL EVALUATION OF BAHMAN DAM SITE

7.1 Summary of Activities Carried Out

The hydrological activities began with a review of a number of documents, including the following resources:

- Institute of Water Management Projects, Moscow
- Sana'a University Water Resources Centre (WEC)
- World Bank Project Appraisal Document for the SBWMP
- Feasibility Study of Al-Jaef Dam Site, Hydrosult

Field visits were made to the Bahman check dam site on several occasions to evaluate it from a hydrogeological perspective. Local groundwater related issues were discussed with the inhabitants of the dam site area.

On the basis of field geological and hydrogeological observations, collection of well inventory data, and available aquifer data, an aquifer study analysis at the dam site has been completed. The issues related to hydrogeological economic and social net benefits, hydrogeological limiting factors and solutions/ alternatives, negative hydrogeological impacts and mitigations, proposed groundwater monitoring systems and hydrogeological performance criteria are discussed in this section.

7.2 Activities Removed from Scope of Work by Client

The following activities were removed from the hydrogeological Scope of Work by the PCU in the Sana'a Basin Water Management Project. Several of these tasks will be completed by other consultants under other SBWMP initiatives.

- Conceptualizing and Groundwater Modeling for simulations of anticipated groundwater flow beneath each dam site.
- Aquifer Monitoring
- Water Balance Studies
- Water Quality Surveys

7.3 Documents Reviewed

1. Sana'a Basin Water Resources Scheme Volume I, Part II Climate and Hydrogeology (Table, Graphic) by WMPC Moscow (1986)
2. Sana'a Basin Water Resource Scheme Volume II, Part II Plots-Geology and Hydrogeology by WMPC Moscow (1986)
3. Sana'a Basin Water Resource Management Study – Basin Characterization Selection of Pilot Study Area – Volume II, Water Resources (Final Report) by Sana'a University (WEC) 2001
4. Sana'a Basin Water Resources Management Study – Volume III – Resources and Environmental Assessment : i) Water Balance Calculation; ii) EIA; iii) Agro Ecology by Sana'a University (WEC) 2001
5. Sana'a Basin Water Resources Management Study – Volume V – Backup Data (Final Report) by Sana'a University (WEC) 2001
6. Preliminary Results of Water Point Inventory by Sana'a University (WEC) 2002
7. WEC-01-2004 by Sana'a University
8. Principal Characteristics of Sana'a Basin – (1) Basin Wide Water Point Inventory; (2) Literature Survey-Part I – Main Report by Sana'a University (WEC) 2004
9. Supply Management Aquifer Recharge Study Volume I – General Report (Final) by Hydrosult Inc. (July 2002)
10. Miscellaneous Report (1) Volume II, Final Report by Hydrosult Inc. (July 2002)
11. Miscellaneous Report (2) Volume III, Final Report by Hydrosult Inc. (July 2002)
12. Feasibility Study of Beryan Dam (Final Report) by Hydrosult Inc. (July 2002)
13. Feasibility Study of Al-Malah Dam (Final Report) by Hydrosult Inc. (July 2002)
14. Feasibility Study of Al-Sinn Dam (Final Report) by Hydrosult Inc. (July 2002)
15. Feasibility Study of Al-Lujma Dam (Final Report) by Hydrosult Inc. (July 2002)
16. Feasibility Study of Al-Ja'ef Dam (Final Report) by Hydrosult Inc. (July 2002)
17. Feasibility Study of Behman Check Dams (Final Report) by Hydrosult Inc. (July 2002)
18. Data Base of Existing Dams in Sana'a Basin Final Report Volume I by General Directorate of Irrigation, Republic of Yemen (July 2001)
19. Data Base of Existing Dams in Sana'a Basin Volume II by General Directorate of Irrigation, Republic of Yemen (July 2001)
20. Project Appraisal Document in Proposed Credits, Republic of Yemen for Sana'a Basin Water Management Project, World Bank (April 2003)
21. Regional Water Requirements for different water consuming sectors by the Technical Secretariat of High Water Council, Yemen (June, 1992)
22. Groundwater Resources by the Technical Secretariat of High Water Council, Yemen (June, 1992)

7.4 Evaluation of Feasibility Studies of Bahman Check Dams Sites by Hydrosult

7.4.1 Aquifer Study

The primary aquifer in Wadi Bahman is of Cretaceous sandstone. The Tertiary and igneous rock caps the upland areas in the catchment. Alluvial deposits fill the wadi bottom with thickness varying from 4 m to 29 m and maximum thickness towards downstream. Average thickness of the aquifer is about 15 m based on VES investigation. The porous and permeable Tawilah sandstone underlies the wadis alluvial deposits as it outcrops along the banks. Second water level occurs at Cretaceous Sandstone at average depth of 49.3 m. Average thickness of aquifer is 136 m.

7.4.2 Water Level Depth

The depth to water levels in open wells along the Bahman Wadi varies from 7.85 m to 15.75 m bgl.

7.4.3 Aquifer Properties

(Hydraulic Conductivity of alluvium layer (k) = 1.9 x 10^{-3} cm/sec

7.4.4 Geophysical Investigation

Three VES were carried out where maximum electrode separation was 1000 m. VES (1) was located downstream of wadi; VES (2) was located at the centre of wadi and VES (3) located at upstream of dam. The following Resistivity Layer Model was prepared based upon feasibility study figures 15a, b and c.

Layers	Resistivity (Ω) m	Description	Depth (m)
1.	2 – 2775	Gravel, sand with clays	4 – 5.85
2.	14 – 50	Saturated weathered mudstone	9.53 – 29
3.	138 - 1285	Hard sandstone	37.3 – 61.25
4.	61 – 124	Saturated sandstone	160 – 211
5.	208 – 583	Hard sandstone	211 – 244
6.	92	Saturated sandstone	> 244

7.4.5 Groundwater Abstraction and Use

Around 33 shallow dug wells of 10 to 15 m depth, and 2 tube wells of 25 m depth, exist in the area. Farmers reported that during run-off, water levels in the wells and discharge increase significantly. The cultivated area is estimated to be 1200 ha in the wadi.

7.4.6 Evaluation

In view of the siliceous nature of the Cretaceous Sandstone, it is essential to quantify the groundwater recharge by lateral flow from reservoirs.

7.5 Bahman Check Dams - Site Evaluation

7.5.1 Geology at Dam Sites

The bed rock and abutment rocks are Tawilah Sandstones. These sandstones are coarse grained with lot of siliceous material. The sedimentary structures like cross-bedding and gradation of sandstone are seen in the wadi. In the upper reaches of the higher slopes of the river bed, there is a deposit of large boulders. Additionally, there is a lot of rock material falling from the side cuttings of wadi. In the middle of the wadi, the course bed is comprised of pebble and sandy beds. In the lower areas of the wadi sandy beds can be found.

7.5.2 Fractures and Joints in Bed Rock and Abutment Rocks

The sandstone here has sheet joints which are conduits for recharging the groundwater in the area.

7.5.3 Tightness of Reservoir

There will be leakage from storage reservoirs formed by series of check dams through the side cutting of the wadi's sandstone beds. As the sandstone is siliceous and hard in nature, there will be more lateral flow from the rims of the reservoirs. With the infiltration through the permeable bed material, there shall be more underflow of the river bed. As the course becomes wider in the middle and lower reaches, there will be greater groundwater recharge as water will remain for a longer period in the reservoirs.

7.5.4 Topography and Drainage Characteristics of Catchment

The Bahman catchment is a vast area with higher contour height as 2720 m and lowest along the wadi of 2400 m above mean sea level. The western mountain parts of catchment are the uplands with steep slopes and near to the wadi on western side the slopes are gentler. In uplands the surface run-off is high. The eastern side of wadi in the upper and middle reaches there is cliff like cutting by wadi. The Bahman Wadi has higher bed slopes in the upper reaches and bed slopes becomes gentler and wider as it flows downwards. In the upper reaches the wadi has brought big boulders because of erosion due to high velocity and also due to side cutting the river course. However, while flowing down into lower reaches the river course becomes wider and area of recharge increases and also the bed load consists of sandy material. There is no vegetation in the whole catchment area which causes more of surface run-off.

7.5.5 Soils

As per the Russian System, the soils at the dam site are mostly Mountain Embryonic Soils pertinent to mountain summits, steep mountain slopes and cliffs, and to rolling plains. They relate to rock outcrops. Generally, they are barren of any grass vegetation. Vegetation may occur when the rough surfaces of these rocks catch at least few centimeters of soil cover. The soils usually occur in combination with mountain gray cinnamon (MG-C) light carbonates under mature soils, and sometimes with shallow medium-deep and MG-C terraced soil varieties. The MG-C light carbonate cultivated soils are found in intermountain depression in the centre of Basin. The texture of these soils is sandy loam, light and medium loam, with some stone and fine rock debris.

7.5.6 Land Use and Crops Grown

(i) Total cultivated land = 54.18 ha.
(ii) Area of Qat farm = 2.22 ha.
(iii) Area of Grape farm = 44.44 ha.
(iv) Other Crops = 8.14 ha.

7.5.7 Hydrometeorological Data

Meteorological Statistics (means over the period 1983-1990) and calculated ETP and E_o Sana'a (CAMA) is as follows in Table 7-1.

Table 7-1: Meteorological Statistics (means over the period 1983-1990) and calculated ETP and E_o, Sana'a (CAMA)*

	TEMP (C)	Relative Humidity (%)	Sunshine Duration (hrs/day)	Wind Speed (m/s)	ETP (mm/month)	E_o (mm/month)
JAN	12.9	64.3	10.4	2.8	150	187.5
FEB	16.8	49.9	4.6	2.7	134	167.5
MAR	19.1	49.4	4.2	3.2	174	217.5
APR	19.6	57.8	7.7	4.4	205	256.25
MAY	21.9	43.8	10.1	3.8	255	318.75
JUN	23.5	41	9.6	4.8	281	351.25
JUL	24	35.8	7.8	4.6	288	360
AUG	23.5	47.7	7.6	4.3	249	311.25
SEP	21.4	39.4	9.5	3.2	223	278.75
OCT	18.5	38.7	1.6	2.9	205	256.25
NOV	15.7	39.5	10.2	2.4	158	197.5
DEC	13	39.4	9.6	2.8	152	190
MEAN	19.2	44.1	8.5	3.5	2475	3092.5

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7.5.8 Hydrological Data

7.5.8.1 Catchment Area

- Total length of main Wadi = 6.40 km
- Slope of main Wadi = 6.0%

- Total length of drainage area = 19.90 km
- Percentage of hilly area = 65%
- Slope of hilly area = 25%
- Average annual rainfall = 186.5 mm

The water level in the wadi rises up to 1.5 m during high flood. This condition occurs about 10 times a year. The high flood remains for approximately 2 hours during a flood event. For four hours after the high flood event, a flow of 10 cm to 15 cm will remain in the wadi.

7.5.9 Well Inventory

There are 50 nos. open wells and 3 nos. tubewells. Twelve open wells and two deep borewells were identified along the course of Bahman Wadi for inventory work. The depth of open well varies from 5.50 m to 28 m and diameter varies from 1.50 m to 3.0 m. The depth of deep borewells is about 300 m bgl.

7.5.10 Aquifer Study Analysis

Tawilah Cretaceous Sandstone is a dual porosity aquifer. The upper aquifer is tapped by open dug wells of varying depth, up to a maximum of about 30 m. The overlying thickness of alluvial material in the wadi beds increases towards its lower reaches. However, geophysical survey carried out show saturated sandstone in depth range of 160 m to 211 m and below 244 m depth. This can be seen in Plate 7-1.

7.5.11 Aquifer Properties

Hydraulic Conductivity of alluvium layer (k) = 1.9×10^{-3} cm/sec

7.5.12 Groundwater Conditions/ Water Levels

Sandstone constitutes the aquifer where bedding planes are permeable. The groundwater flow is from north to south. Fluvial deposits in upper and middle reaches are permeable, whereas in the lower reaches, the silty sands are more porous and very permeable. The depth of groundwater level in open wells along the Bahman Wadi varies from 8.0 to 29 m below ground level (BGL). Similarities can be found in the map of the shallow aquifer water table and piezometric levels in the Bahman Check dam area. Refer to Section 7.9 of this report.

7.5.13 Groundwater Quality

The site lies in the Wadi Al-Sirr hydrogeological zone. This zone is comprised of Tawilah Sandstone of $CaCHO_3$ composition, and EC ranging from 400-800 µs/cm. Hydrochemical results show mixing of groundwater from quaternary deposits, as sandstone outcrops are exposed to the surface. Similarities can be noted in the map of electrical conductivity in the Bahman Check dam area; refer to Section 7.9.

7.5.14 Groundwater Abstraction

Around 33 shallow dug wells of 10 to 15 m depth, and 2 tube wells of 25 m, depth exist in the area. Farmers reported that during run-off water levels in wells and discharge increase significantly. The cultivated area is estimated to be 1200 ha in the wadi.

7.5.15 Water Demand

(i) Irrigation Water Requirement of Crops

Qat and grapes are main crops in the area. As per Sana'a University (WEC) (2001) study report, the irrigation water requirement (IWR) of each crop, qat and grapes alike, is around 8000 m^3/ha. The expected water use efficiency is 75%.

Area cultivated in village Bahman (Al-Jab Baila, Baith Joban)		=	54.81 ha
Area under qat crop		=	2.22 ha
Area under grapes & other fruits	= 44.44 + 8.14 ha	=	52.58 ha

(A) Irrigation Water Requirements = 438,480 m^3
Total Irrigation Water Requirements
With 75% Water Use Efficiency (A) = 548,100 m^3

(ii) Domestic Water Demand

Population in village Bahman (Al-Jab Baila, Baith Joban) = 4,500
Rural Domestic Water Demand @ 21 l/d/head = 4,500*21 = 94,500 l/d
= 94.5 m^3/d/head
= 34,492 m^3/yr

(iii) Livestock Water Demand

No. of livestock (cow, sheep, donkey) = 2,000
Water Demand of livestock = 2,000*10.9 = 21,800 m^3/yr

Total Water Demand (A + B + C) = 548,100+34,492+21,800
= 604,392 m^3/yr

As per the High Water Council, Yemen, Report on Regional Water Requirements, the projected annual growth rate of crops qat and grapes is less than 3%. Also, per capita water consumption increases 1.5 percent annually in Yemen.

7.6 Hydrogeological Economic and Social Net Benefits

The effective use of groundwater can occur when the benefits of utilization outweigh the costs over a given period of time. It is not economical to abstract groundwater at a rate greater than the recharge rate. For this reason, long-term pumping rates should not exceed long-term recharge rates for any given aquifer. Efforts should be made towards the judicious use of groundwater resources within safe pumping limits. Over-exploitation of the groundwater resources should be avoided whenever possible.

Remedial measures to rehabilitate an aquifer are certainly more costly than measures that are taken to monitor and control water use. It also takes a longer time to rehabilitate a damaged aquifer system with limited financial resources. The socio-economic status of the inhabitants living near an aquifer will increase as the aquifer experiences an improvement in groundwater levels and quality. Proper water usage, and reduced wastage of water, is anticipated byproducts of a successful recharge program. Regular monitoring of groundwater levels should be carried out so that the desired standard of water quality is maintained.

General Economic and Social Benefits

1. The benefits from the recharge to groundwater by the construction of new check dams would be felt over a period of time, and will mostly be of indirect nature.
2. With the groundwater levels declining annually, the farmers have to resort to spending money on replacement of their existing pumps with high head pumping systems. However, with implementation of recharge prospects, the farmers may be able to end costly expenditures on new pumping systems.
3. There will be a manifold increase of agriculture area. Commercial crops of high economic return can be grown with the availability of irrigation water from dug wells and borewells.
4. Open dug wells which have become dry will be restored when the water levels rise in the aquifer.
5. Farmers and villagers will not have to resort to drilling new, deeper borewells. Aquifer levels should rise as recharge is improved.
6. A stable or rising groundwater level may result in energy savings to well users. Deep tubewells require the use of pumps to bring water up from depressed water tables. As the water levels rise, less fuel will be required to draw water out of the well.
7. New drinking water facilities should be created in downstream villages. These benefits are of immense importance.
8. There shall be an increase in employment potential by use of local labor--both skilled as well as semi-skilled.
9. The Per Capita Income of local people should be increased, and this will provide for a higher standard of living.

10. Local peoples' participation in the development work enhances its overall benefits.
11. Environmental improvements help in controlling the pollution hazards.
12. There shall be increase in investments/ institutional finances for construction work.
13. Anticipated impact of change in water use in downstream areas should have community participation.
14. Investment in wells, pumps, diversions and conveyance system which are fixed assets will increase.
15. The use of qat is widespread and growing. It is controversial in terms of its socio-economic impact. Qat is highly profitable for farmers, and it may hurt as much as help the average family's budget. Excessive monies spent on qat may deprive families from other necessities. There is need to provide agricultural extension services to educate farmers to diversify to other commercial crops such as grapes.

Bahman Site-Specific Hydrogeological Economic and Social Benefits

1. Improved recharge within the wadi will occur. The check dams will impede the progress of water down the wadi, allowing it to infiltrate the aquifer all along the length of the dam. This will improve agricultural yields along the wadi's length.
2. High level of public awareness about the benefits of recharge should result in a desire for local O&M of check dam system.
3. Education and awareness about the O&M of check dams should result in reduced solid waste pollution in the wadi.
4. Bahman will act as a pilot check dam project. Proper monitoring of the instrumentation will result in solid data generation and recording. This will improve the evaluation of the feasibility of future check dam projects in the Sana'a Basin and elsewhere in Yemen.

7.7 Hydrogeological Limiting Factors and Solutions/ Alternatives

The sandstone in the wadi is highly hard and siliceous. There is little possibility for groundwater recharge from the bed rock which lies below the alluvial material. However, there will be recharge from lateral flow due to larger horizontal component of permeability along the bedding planes of the sandstone.

7.8 Negative Hydrogeological Impacts and Mitigations

1. In order to obtain high-quality, relatively uncontaminated water in a groundwater recharge project, silt-free water is a necessity. Run-off water from the catchment area will contain suspended silt and other sediments. These sediments will be deposited in the reservoir bottom. Build-up of sediment over time may have an adverse affect on the recharging process in only a few years' time.

   One method of mitigating this problem is the construction of gabion structures from locally available rock and steel wire cages. These gabions could be located in mid-uplands and lowland areas of the catchment basin in order to trap sediments and reduce their impact upon the reservoir's recharge.

2. It is possible for the reservoir to experience clogging through the activity of biological blooms and organisms. The extent and severity of this activity depends upon the mineral and organic composition of the water and the basin floor. Biological clogging of the reservoir will retard the rate of groundwater recharge. Feasible methods of treating this biological activity include removal of organic materials from the basin after it has been emptied; scraping the basin floor; or adding some chemicals to the water to retard biological growth. The costs of performing this work would be part of the O&M expenditures for maintenance of the dam.

3. Reduced sediment and nutrient replenishment in downstream areas may also occur if the check dams are not properly maintained.

7.9 Development of Groundwater Monitoring System

It is essential to monitor the response of groundwater regime to the construction of new dams/ rehabilitation of existing dams in the downstream areas. The data base generated forms the basis for future groundwater development and management. Due to the lack of available data for check dams in the Sana'a Basin, the Bahman Check Dams may be considered to be a "pilot project" of sorts. Careful monitoring and observation of the performance of these dams will be important to determining their ability to be successfully replicated in other locations.

There is a need to establish an observation network for the dug wells if available, and for constructing piezometers to study the effect of groundwater recharge from the check dam storage reservoir upon the groundwater levels. Finally, study of the effect of groundwater pumping from shallow open wells/ borewells upon the water table can be observed. These observation wells can also be used for monitoring groundwater quality. (See the maps of the Target Area Location, shallow aquifer water table, piezometric water level, electrical conductivity, temperature and pH in the Bahman dam area) as reference base maps for further monitoring.

The proposed locations of observation wells/ piezometers for monitoring groundwater levels near the dam sites are given below. Three piezometers located in perpendicular section to the wadi are proposed in Bahman Village to observe lateral groundwater flow from wadi into the sandstones (see Table 7-2 below). While these piezometers are not part of the check dam design, they can easily be incorporated into a monitoring program by the local WUA.

Table 7.2. Proposed Observation Wells and Piezometers.

Observation Wells (OW) Piezometer (Pw)	Location		Depth in m (bgl)
	Easting	Northing	
OW-1	442172	1716593	27.00
OW-2	441501	1715790	18.00
OW-3	441341	1715038	16.00
PW-1	441353	1716323	50.00
PW-2	441306	1716380	50.00
PW-3	441518	1716046	50.00

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s.no	Well no	UTM N	UTM E	Elevation	Water level	Conductivity	Temperature	pH
1	A-0550	1693922	436099	2640.00	18	362	20.30	8.1
2	A-0551	1693864	436090	2638.00	2.0	338	21.0	8.0
3	A-0553	1693931	436045	2631.00	5.0	346	20.0	7.7
4	A-0554	1693907	435852	2619.00	9.6	333	21.5	7.5
5	A-0556	1693746	435356	2586.00	8.7	654	20.6	7.2
6	A-0562	1692827	435671	2588.00	3.5	697	20.0	7.5
7	A-0563	1692849	435696	2599.00	9.5	413	18.7	8.1
8	A-0565	1692929	435519	2581.00	10.0	437	19.0	7.5
9	A-0566	1692975	435283	2580.00	8.2	400	21.0	8.2
10	A-0567	1693881	435195	2595.00	5.4	530	22.0	7.4
11	A-0570	1693598	434667	2567.00	4.7	373	20.8	7.2
12	A-0571	1693402	434929	2569.00	4.2	373	20.8	7.2
13	B-0133	1708279	431427	2343.00	45.4	910	17.0	7.9
14	B-0263	1708264	428411	2294.00	32.0	754	17.4	7.3
15	BS-0450	1714106	445076	2394.00	26.2	926	22.1	7.8
16	BS-0452	1714050	445158	2399.00	23.2	502	21.4	8.0
17	BS-0453	1714190	444908	2398.00	24.6	1050	22.1	8.1
18	BS-0456	1714569	444453	2417.00	21.5	383	22.5	7.8
19	BS-0459	1713361	444268	2387.00	31.9	455	21.7	8.8
20	BS-0461	1713905	444670	2388.00	31.6	428	21.7	8.0
21	BS-0464	1714536	444295	2419.00	19.2	2250	20.2	9.1
22	BS-0465	1714772	444041	2422.00	7.8	462	20.8	8.0
23	BS-0466	1713493	444599	2389.00	13.0	540	19.9	8.0
24	BS-0468	1713183	445521	2402.00	15.0	434	20.5	8.4
25	BS-0469	1713142	445510	2393.00	10.5	450	21.0	8.0
26	BS-0505	1713957	443667	2383.00	17.9	891	22.2	7.5
27	BS-0916	1714645	442832	2374.00	17.7	459	22.0	8.3
28	BS-0917	1714832	442981	2377.00	17.7	625	21.7	8.0
29	BS-0918	1714829	443037	2382.00	22.9	742	20.5	7.6
30	BS-0919	1714837	442909	2384.00	24.5	490	21.7	8.4
31	BS-0920	1714934	442938	2376.00	16.3	650	20.7	7.8
32	BS-0924	1713158	440720	2337.00	16.8	937	18.3	7.6
33	BS-0927	1713158	440227	2335.00	31.4	1230	18.4	7.5
34	BS-0928	1713202	440244	2338.00	25.3	1289	19.9	7.5
35	BS-0929	1713236	440232	2330.00	21.8	1270	20.0	7.4
36	BS-0931	1713310	440309	2335.00	21.2	1100	20.2	7.7
37	BS-0933	1714333	442992	2381.00	21.7	680	22.6	7.9
38	BS-0934	1715098	443116	2391.00	17.4	911	20.4	8.0
39	C-1335	1719677	433010	2220.00	7.4	1070	20.4	8.0
40	C-1337	1719427	432989	2223.00	12.7	2160	18.6	6.7
41	C-1338	1719127	433397	2244.00	12.6	590	21.7	7.6
42	C-1339	1718892	433420	2246.00	11.1	779	22.2	7.4

43	C-1341	1718785	432364	2258.00	13.5	374	19.9	8.0
44	C-1343	1718738	433357	2247.00	16.8	2730	18.0	8.3
45	C-1346	1713996	433344	2236.00	19.6	2320	19.7	7.4
46	C-1347	1718970	433243	2232.00	21.7	1660	21.1	7.7
47	C-1350	1719150	433263	2228.00	25.8	2230	23.5	7.3
48	C-1351	1719141	433304	2231.00	12.2	2910	20.0	7.9
49	C-1354	1719431	433274	2221.00	17.8	1900	21.2	6.8
50	C-1355	1719446	433170	2225.00	11.8	2430	22.5	7.1
51	C-1357	1719526	433482	2230.00	20.5	2000	21.9	7.3
52	C-1359	1718929	434012	2252.00	13.5	692	22.6	7.2
53	C-1360	1718860	433997	2264.00	14.5	355	21.3	7.4
54	C-1364	1718800	433944	2246.00	6.6	628	19.7	7.4
55	C-1365	1718887	433892	2247.00	8.6	608	21.4	7.3
56	C-1366	1718925	433913	2244.00	3.1	715	19.8	7.7
57	E-1020	1717281	439422	2361.00	1.5	1260	24.6	8.6
58	E-1023	1718852	440377	2443.00	4.5	1220	24.5	7.8
59	E-1025	1718960	440337	2462.00	4.5	1270	22.7	8.2
60	E-1026	1719022	440323	2469.00	10.4	1110	25.1	7.4
61	E-1027	1719040	440331	2472.00	6.0	1320	22.1	7.8
62	E-1030	1718965	440750	2495.00	20.1	534	28.1	7.6
63	E-1032	1718890	440814	2524.00	20.2	270	25.1	8.4
64	E-1033	1718945	440648	2485.00	4.0	493	25.1	7.8
65	E-1034	1718902	440606	2476.00	13.0	745	20.3	8.5
66	E-1038	1719819	440312	2530.00	10.7	256	24.2	7.6
67	E-1043	1715876	437832	2325.00	10.0	1950	21.0	7.6
68	E-1044	1716082	437777	2332.00	7.8	1460	25.1	7.6
69	E-1045	1716074	437708	2342.00	11.0	1760	21.7	7.9
70	E-1047	1716226	437776	2336.00	9.2	1350	20.1	7.8
71	E-1048	1716247	437817	2332.00	7.7	2450	19.4	8.2
72	E-1050	1716310	437814	2325.00	7.3	2290	25.1	7.1
73	E-1052	1716382	437797	2343.00	58.0	1730	25.1	7.2
74	E-1053	1716431	437830	2334.00	8.2	2090	20.2	7.7
75	E-1056	1716631	437803	2349.00	10.5	2440	22.7	7.5
76	E-1057	1716607	437759	2350.00	4.0	1520	20.4	7.5
77	E-1059	1716797	437703	2372.00	6.3	1110	22.10	7.5
78	E-1069	1717800	437253	2400.00	6.4	1265	20.5	7.3
79	E-1070	1717800	437180	2405.00	4	1758	21.3	7.3
80	E-1072	1717939	437321	2422.00	4	637	21.1	7.3
81	E-1073	1717885	437356	2373.00	8	877	20.2	7.3
82	E-1074	1717661	437430	2375.00	9	900	20.7	7.3
83	E-1692	1693697	431267	2513.00	20	270	22.3	8.2
84	E-1693	1693735	431185	2507.00	21	324	19.7	8.6
85	E-1695	1694111	431829	2503.00	14	327	20.1	8.6
86	E-1800	1695874	433355	2541.00	26	347	21.0	7.9
87	E-1803	1697472	432408	2465.00	22.9	760	19.4	7.5
88	E-1804	1697564	432441	2477.00	16.0	1100	18.8	7.7
89	E-1805	1697529	432585	2470.00	15.0	1340	19.7	7.8

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TABLE OF PIEZOMETRIC WATER LEVELOF SHALLOW AQUIFER
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S.No	Well No.	UTMN	UTME	ELEV/m	Piezometric Water Level	Water Level Per Meter
1	A-0550	1693922	436099	2640	2622	18
2	A-0551	1693864	436090	2638	2636	2
3	A-0553	1693931	436045	2631	2626	5
4	A-0554	1693907	435852	2619	2609	10
5	A-0556	1693746	435356	2586	2577	9
6	A-0558	1693789	435361	2587	2581	6
7	A-0562	1692827	435671	2588	2585	4
8	A-0563	1692849	435696	2599	2590	10
9	A-0564	1692963	435647	2594	2585	9
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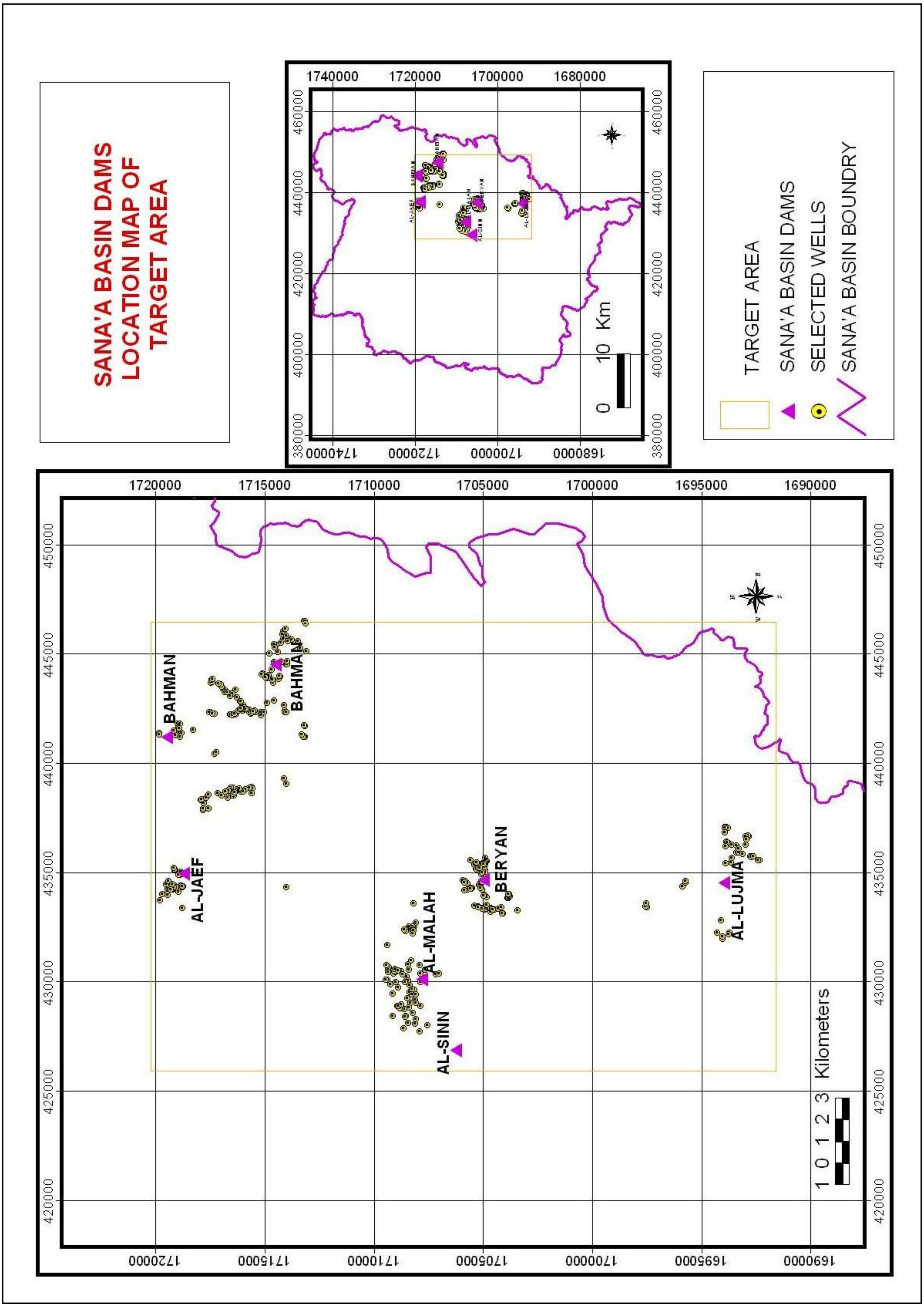
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SELECTED WELLS
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Kilometers
1 0 1 2 3
BAHMAN
BAHMAN
AL-JAEF
AL-MALAH
AL-SINN
BERYAN
AL-LUJMA
1720000
1715000
1710000
1705000
1700000
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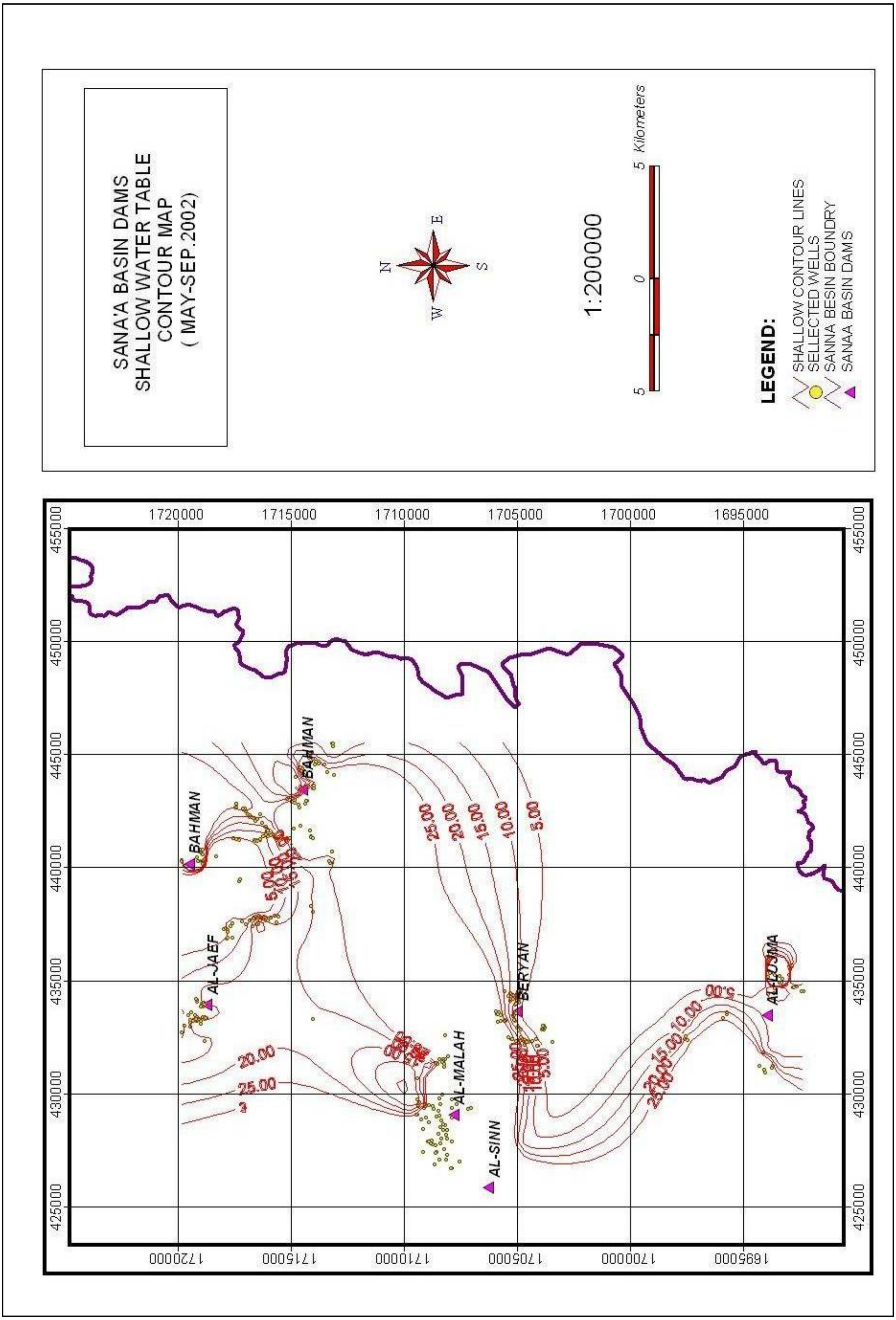
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SHALLOW CONTOUR LINES
SELLECTED WELLS
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SANAA BASIN DAMS
BAHMAN
BAHMAN
AL-JAEF
AL-MALAH
AL-SINN
BERYAN
AL-LUJMA
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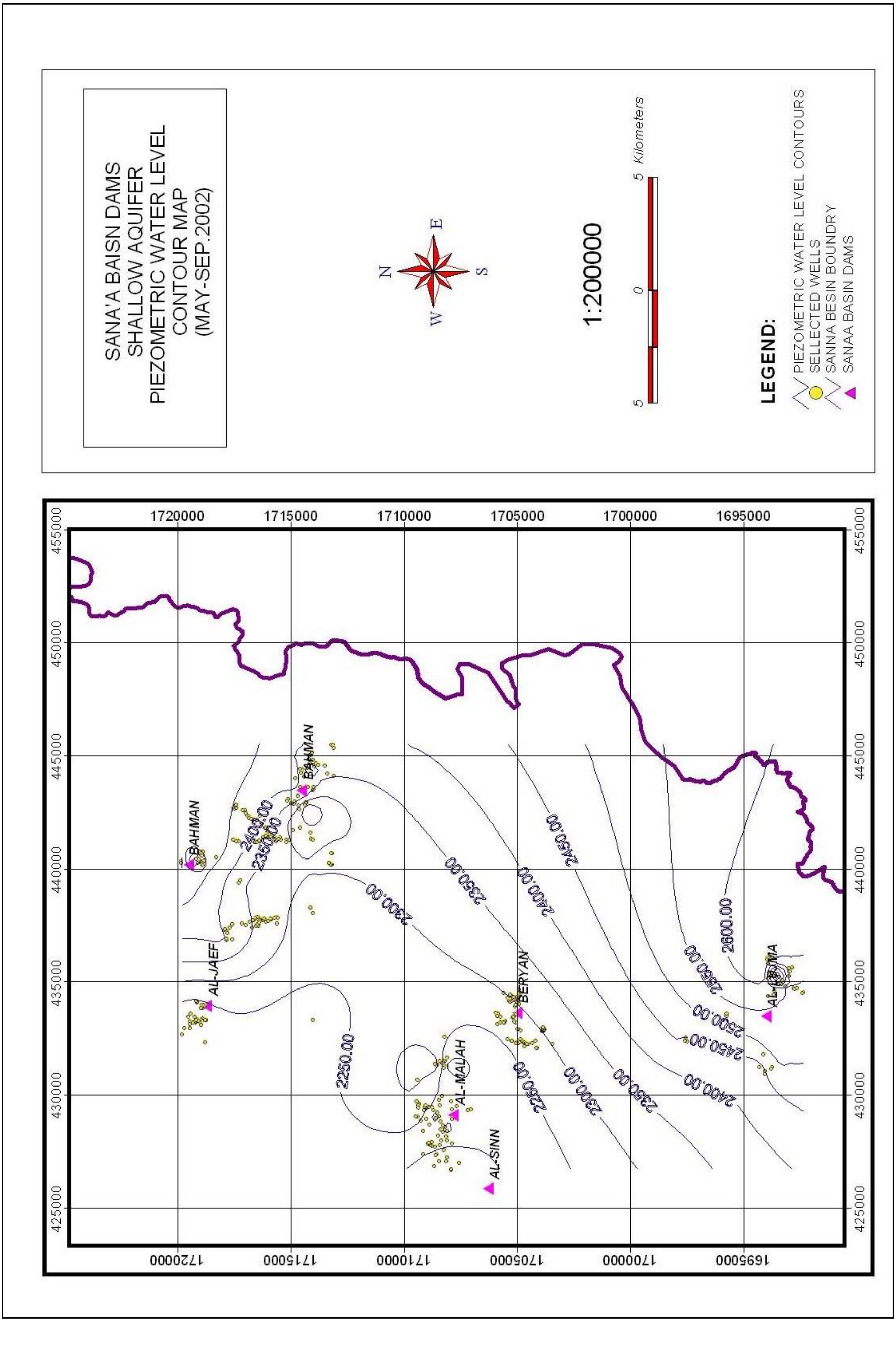
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BAHMAN
AL-JAEF
BAHMAN
AL-MALAH
AL-SINN
BERYAN
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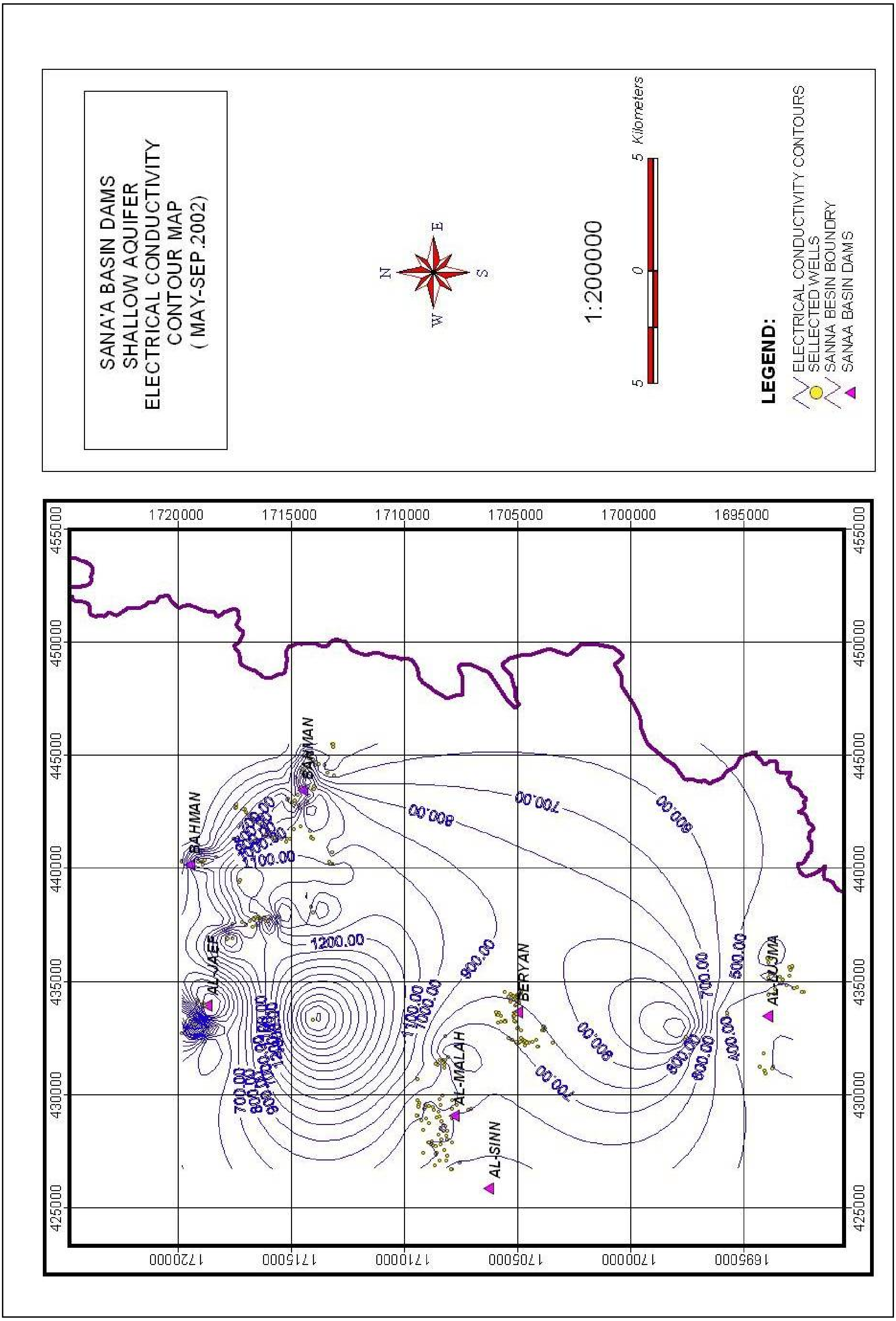
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SHALLOW AQUIFER
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LEGEND:
ELECTRICAL CONDUCTIVITY CONTOURS
SELLECTED WELLS
SANNA BESIN BOUNDRY
SANAA BASIN DAMS
BAHMAN
SAHMAN
AL-JAEF
BERYAN
AL-MALAH
AL-SINN
AL-JUJMA
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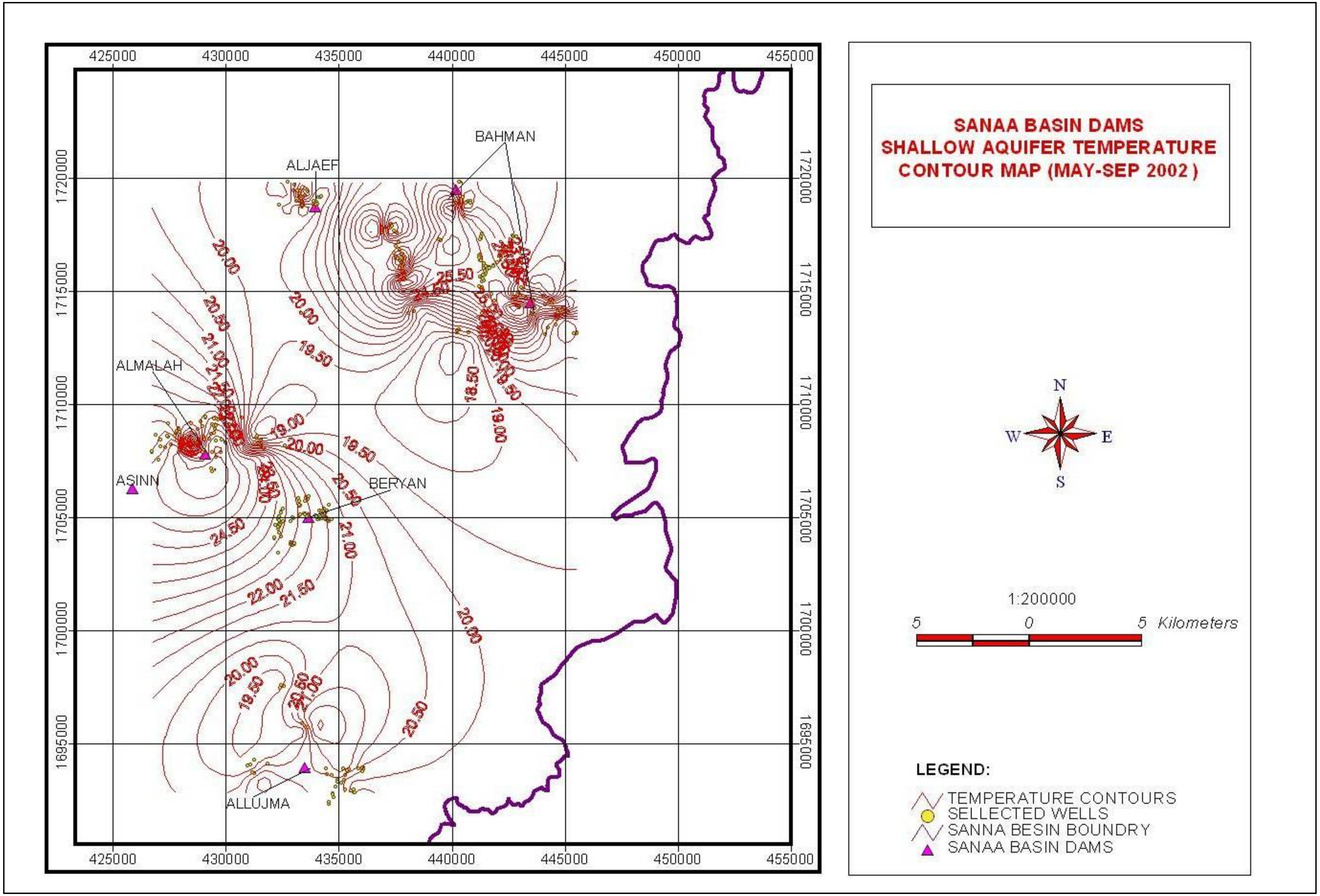
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LEGEND:
TEMPERATURE CONTOURS
SELLECTED WELLS
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SANAA BASIN DAMS
BAHMAN
ALJAEF
ALMALAH
ASINN
BERYAN
ALLUJMA
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440000
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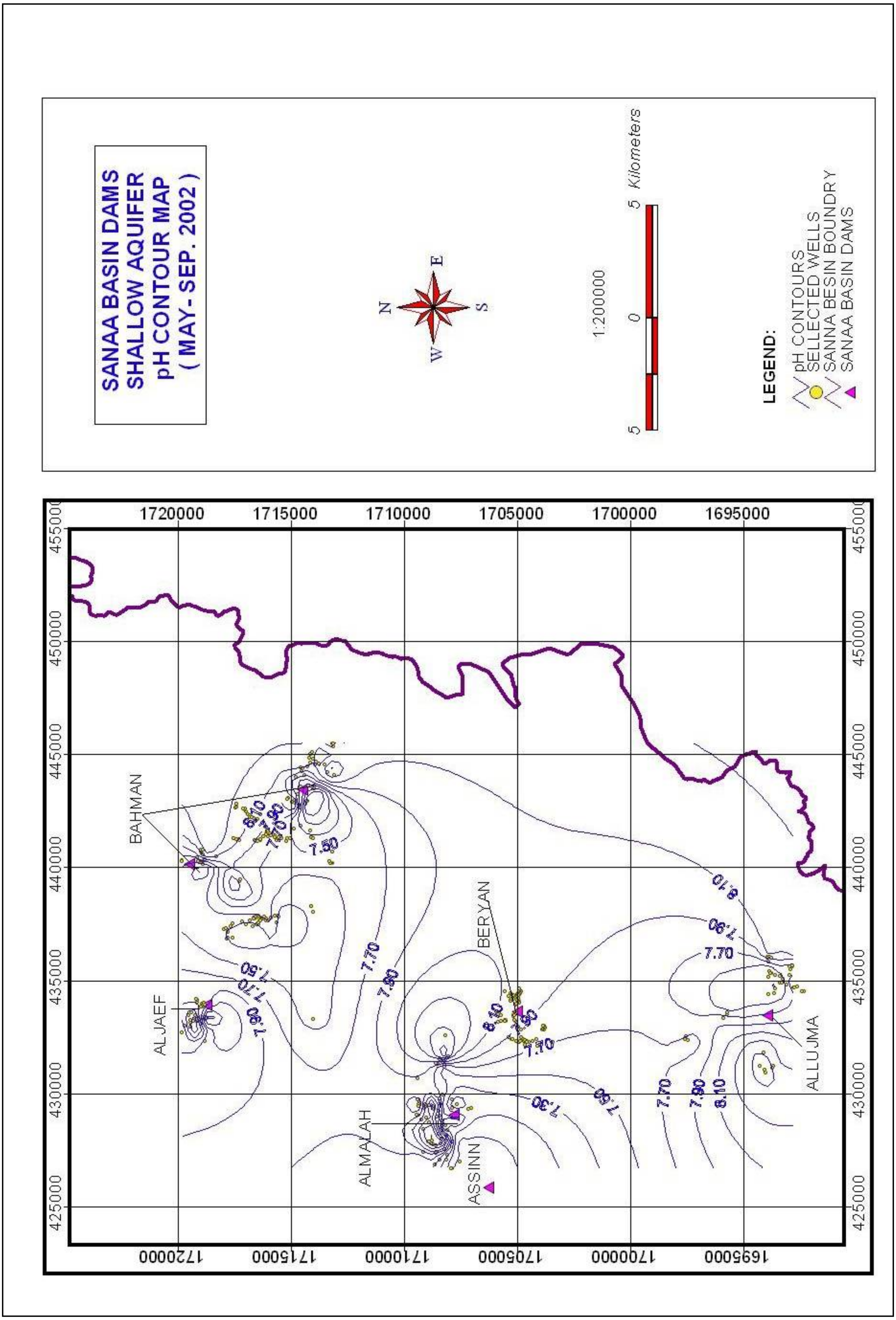
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SHALLOW AQUIFER
pH CONTOUR MAP
(MAY- SEP. 2002)
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S
W
1:200000
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LEGEND:
pH CONTOURS
SELLECTED WELLS
SANNA BESIN BOUNDRY
SANAA BASIN DAMS
BAHMAN
ALJAEF
ALMALAH
ASSINN
BERYAN
ALLUJMA
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9.0 Hydrogeological Performance Criteria

The impact of artificial recharge in both time and space on the groundwater regime, and its technical analysis, are helpful in assessing the efficacy of artificial recharge structures. In addition, the evaluation of this impact but would go a long way in optimally designing and locating pumping wells and recharge facilities. This will contribute to a proper water management program.

The following criteria will help in hydrogeological performance:

1. Groundwater Monitoring Network has been proposed to study the effect of groundwater recharge project on the groundwater regime in downstream areas.
2. The groundwater quality of samples collected from observation wells/ piezometers will also be monitored.
3. The observations of groundwater level depth should be taken at least 3 times a year, i.e. in the months of February, June and October, as part of a monitoring program.
4. The monitoring of the groundwater balance of the watershed is another criterion to study the program.
5. The increase in production of existing crops, diversification to commercial crops, and overall increase in the annual income of farmers should be monitored.
6. Lowering of energy consumption due to replacement of higher BHP motors to lift groundwater by lower BHP motors is other criteria of hydrogeological performance.

SECTION EIGHT: FINAL DAM DESIGN AND TENDER DOCUMENTS

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SECTION EIGHT: FINAL DAM DESIGN AND TENDER DOCUMENTS

8.1 Check Dam Types

Due to non-availability of suitable site for a reservoir dam, the design team concurred with the Hydrosult concept of adopting a series of check dams in the Bahman wadi. However, site reconnaissance and evaluation led to the location of additional check dams. Initially six additional dams were proposed, for a total of 29 check dams. After technical review with AEC and GDI, this number was reduced to 27. These new check dams, as well as the existing check dam structures that were built locally, will retain and retard the flow of storm waters within the wadi. This retention of water will facilitate the recharge of the ground water table. Check dams will be made of rock piles where size of the boulders is selected to withstand flow velocities.

Check dams are simple to construct and should be programmed to execute in between rainy seasons. Due to the scattered sites a number of gangs can be used to expedite the works.

Flow measurement device in the form of a Parshall Flume and a number of piezometers are planned for ground water table monitoring. Monitoring of the flows and recharge within the check dam cascade will be important to the overall future of check dam systems in Yemen. The lack of complete data at any other check dam location may require that this check dam series be considered a "pilot project." Additional discussion on the monitoring requirements for the Bahman Check Dam are discussed in Section 14.

8.2 Tender Documents

The Bidding Documents for the Bahman Check Dams have been prepared. They consist of the following items and volumes:

Volume 1	Bidding Document
Volume 2	Specifications
Volume 3	Drawings

Priced BOQs were prepared and submitted under confidential cover.

SECTION NINE: DAM DESIGN

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SECTION NINE: DAM DESIGN

9.1 Check Dams Design

Due to the relatively small catchment area of the Wadi Bahman and non-availability of a proper site for a reservoir, a series of check dams were proposed at this site. The purpose behind the check dams is twofold: One, to retard the runoff; and Two, to encourage improved recharge the shallow groundwater aquifer through the alluvium layer. Several existing and proposed wells in the wadi will be recharged through the ponding of water upstream of the check dams. The feasibility study report proposed 23 check dams along the entire length of the wadi. The stream of the wadi was defined and found to be 4,698 m long. The number of check dams to be constructed and operational at the Bahman site has been increased to 27 by introducing 5 additional structures and removing one of the proposed check dams in the feasibility study. Determining of new check dam locations was completed as part of the site reconnaissance for the proposed check dams, and through technical discussions with Arcadis Euroconsult (AEC) and the PCU.

9.2 Typical Sections

Upon commencement of the detailed design stage, general design criteria were established. For improved access to the wadi bed and check dams, and to simplify the construction, the upstream and downstream side slopes of the check dams have been adjusted to 3H:1V and 5H:1V, respectively, and the crest width set to 2 m. A foundation key was also added to the adjusted section. This key will improve dam performance against sliding, improve overall stability, and improve resistance to the hydraulic pressures that will act on the dams. Upon setting these general design criteria, a detailed study of each of the check dams was undertaken.

Each check dam site was investigated for surrounding rechargeable wells that might benefit from the dam. In several locations of the proposed check dams, rechargeable wells were identified. Where applicable, the top elevation of the wells was used in setting the check dam crest height in order to maximize the dam's recharging capacity. However, in other other cases, the proposed check dams were not close enough to rechargeable wells, and were therefore placed for stream training purposes.

The check dams are planned to be constructed using free-draining rocks. This material will allow the first flood to penetrate the check dam body along with all sediments carried by the flow. The sediments will then be deposited inside of the check dam body in order to form a more stable structure. The presence of these sediments will also reduce the permeability of the check dam body. The repetition of the flood flows through each check dam will enhance its stability over time, and will reduce the permeability to than of an almost impermeable structure. It is estimated that this state will be reached after one rainy season.

In determining the final check dam height, the lowest point in the existing ground surface was used as the dam base elevation. Wherever there existed a well that had a potential to be recharged by the introduction of the check dam, the height of the dam was set in such a way as to maximize the recharge benefit of the dam, so that the upstream reservoir is extended to reach the concerned well. In other occasions where the check dams were used for stream training, their heights have been adapted as proposed by the original study of Hydrosult.

These heights may be revised if specific requirements from the client or site conditions warrant such revisions, subject to the evaluation and approval of the supervising Engineer. Check dam heights ranged between 1 and 3m. The dams are drawn on the plan according to the established design criteria; therefore, the dam bases and dam crest lengths and elevations are established accordingly. A sample of a typical dam plan is shown in **Figure 9.1**.

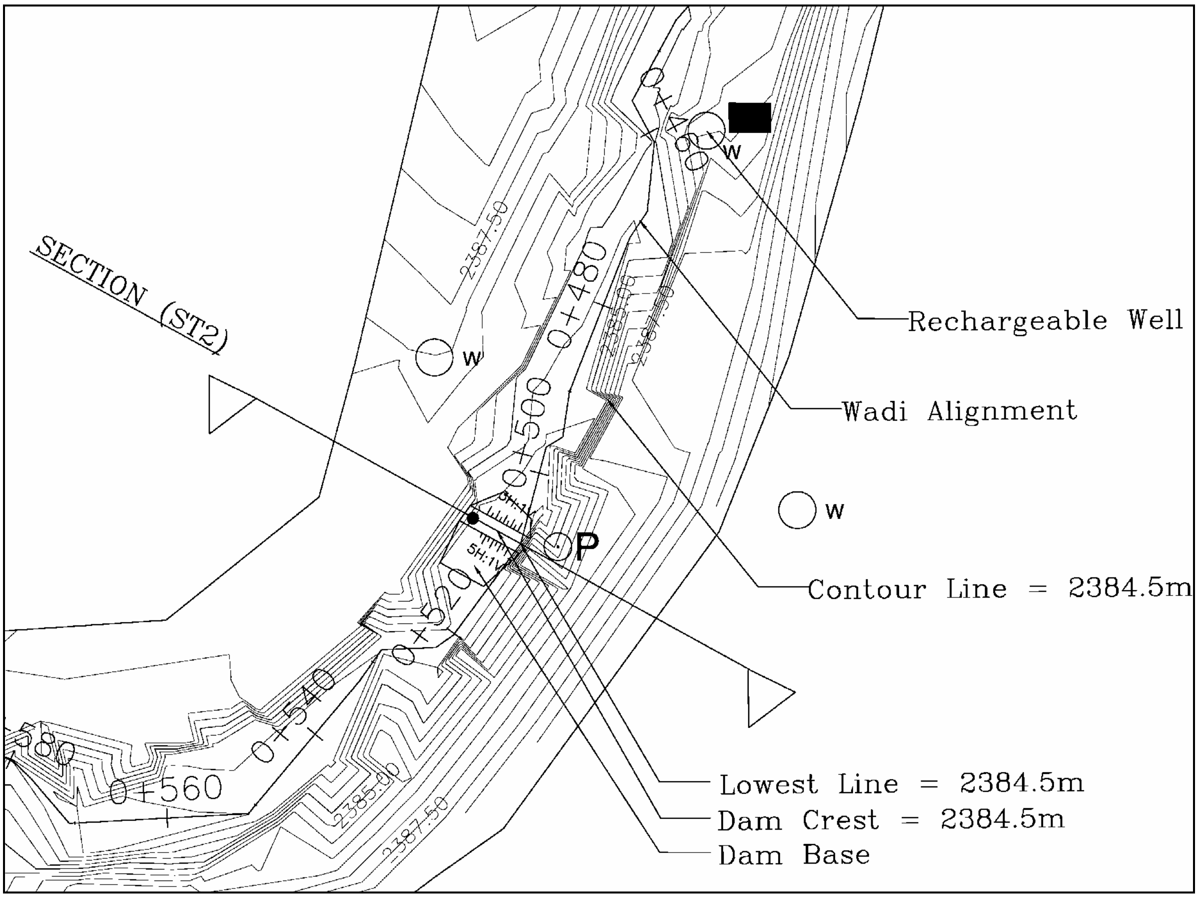


Figure 9.1: Sample of Check Dam Plan.

A complete profile of the wadi alignment was drawn, and all check dams and relevant wells placed on it as shown in the sample profile in **Figure 9.2** below. The Complete plan and detailed profiles are presented in Volume III – Drawings.

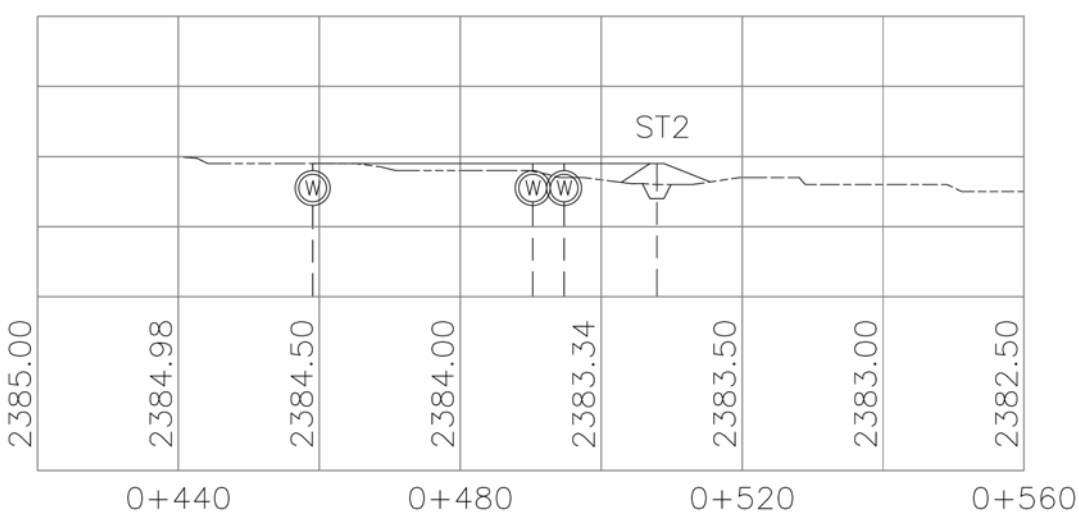
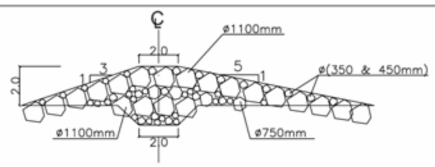
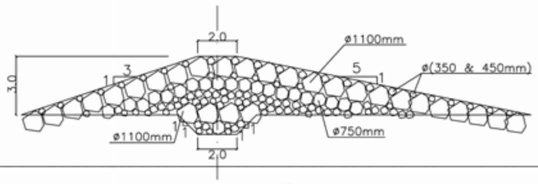
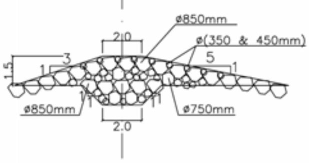
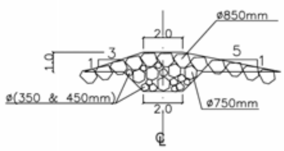


Figure 9.2: Sample of Check Dam Profile.

The final design included the development of four different typical check dam cross-sections is shown in **Table 9.1**. **Table 9.2** lists the characteristics of all check dams.

Table 9.1. Typical Check Dam Cross Sections.

Type of Typical Section	U/S D/S	Check Dams
Type 1		HA, HE, HF, HJ, HS, HT & ST5
Type 2		ST1 & ST3
Type 3		HB, HC, HD, HH, ST2 & ST4
Type 4		HG, HI, HK, HL, HM, HN, HO, HP, HQ, HR, HU & HV

Review of the check dam profiles in the drawings will reveal that the downstream slopes of some of the dams are extended for a significant distance downstream. The reason for these shallow slopes is to enhance access over the dam, particularly when the terrain is irregular.

In the event of rough terrain, smoothing of the wadi bed enhances the flow characteristics of the site. The best available survey information has been used in the check dam designs. However, modifications by the contractor, with review and approval by the Engineer, may be required during construction due to changing conditions within the wadi.

A check dam that was proposed between check dams T and U, at station 4+185.05, was eliminated from the design for the following reasons:

- Its location does not provide sufficient storage area due to the flatness of the upstream ground,
- No rechargeable wells are located close by,
- Its closeness to the next check dam limits its performance in stream training.

Table 9.2. Summary of Check Dams Characteristics.

Typical Section Type	Check Dam	Station	Top width	Dam height	Wadi Bed Elevation	Dam Crest Elevation	Crest Length
	ID	(km+m)	(m)	(m)	(masl)	(masl)	(m)
2	ST1	0+366.26	2	3	2386	2389	23.45
3	ST2	0+507.90	2	1.5	2383	2384.5	7.44
2	ST3	0+611.50	2	3	2381.5	2384.5	25.12
1	HA	0+820.32	2	2	2374.52	2376.52	12.75
3	ST4	0+946.17	2	1.5	2373.45	2374.95	19.08
3	HB	1+072.18	2	1.5	2370.52	2372.02	17.85
3	HC	1+218.19	2	1.5	2369	2370.5	33.93
1	ST5	1+323.03	2	2	2367	2369	43.62
3	HD	1+393.78	2	1.5	2366.5	2368	47.71
1	HE	1+488.34	2	2	2362.6	2364.6	21.94
1	HF	1+767.06	2	2	2359	2361	16.67
4	HG	1+955.33	2	1	2356.86	2357.86	18.56
3	HH	2+061.56	2	1.5	2353.11	2354.61	23.59
4	HI	2+180.13	2	1	2351.5	2352.5	31.13
1	HJ	2+360.66	2	2	2349.44	2351.44	31.29
4	HK	2+403.72	2	1	2348.87	2349.87	27.22
4	HL	2+485.07	2	1	2347.5	2348.5	32.04
4	HM	2+616.64	2	1	2346	2347	32.58
4	HN	2+778.22	2	1	2344.5	2345.5	43.53
4	HO	2+930.28	2	1	2343.5	2344.5	37.74
4	HP	3+082.35	2	1	2340	2341	17.37
4	HQ	3+320.00	2	1	2337.5	2338.5	25.74
4	HR	3+526.94	2	1	2336	2337	44
1	HS	3+706.04	2	2	2332.5	2334.5	57.66
1	HT	4+063.25	2	2	2328.76	2330.76	43.87
4	HU	4+436.46	2	1	2322.5	2323.5	10.07
4	HV	4+568.75	2	1	2322	2323	10.78

9.3 Slope Stability and Rock Sizing

Rip-rap failure modes include particle erosion, translational slide, modified slump, and slump. Translational slide, modified slump, and slump are slope or soils processes. Particle erosion is a hydraulic phenomenon, which results when the tractive force exerted by the flowing water exceeds the riprap materials' ability to resist motion.

An important parameter required for the calculations of the riprap sizing is the flow or velocity of flow. Therefore, a method known as Slope-Area was used to estimate the flow in the wadi (as explained below) and an average flow of 119 m^3/s was determined.

Hydrological analysis was conducted to estimate inflow values for Wadi Bahman as follows:

Q_{100}	97.31 m^3/s
Q_{500}	113.6 m^3/s
Q_{2000}	165.98 m^3/s

The slope-area method used to estimate the flow in the wadi made use of the information reported by the farmers. They stated the floods may last for 3-5 hours and may reach 1.5 – 2m in depth within the wadi. Other information used in estimating the flow includes the cross-sectional characteristics of the wadi, and reports that the wadi floods 6-10 times per year. A reach (a profile along the wadi) is chosen to act as a representative profile for consideration for the design.

Figures 9.3 and **9.4** present a reach in plan and the three cross-sections cut along the reach, respectively.

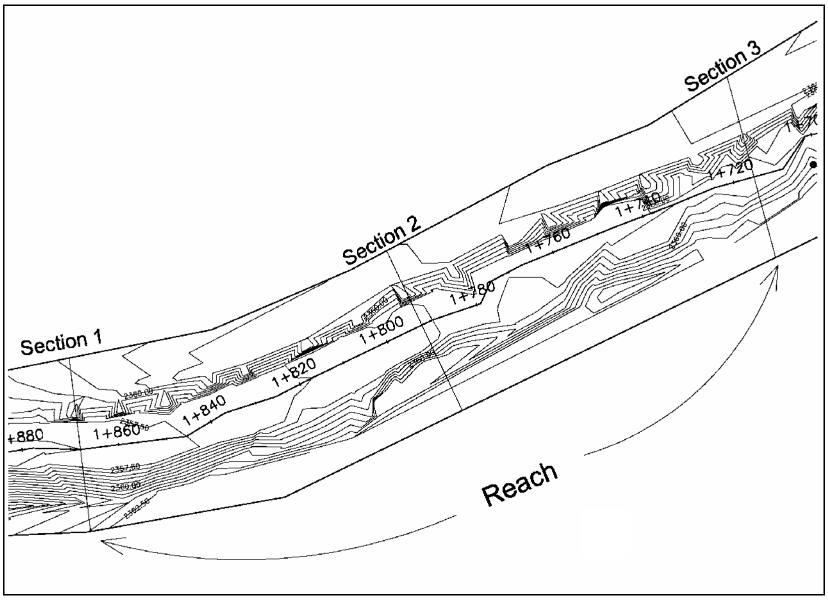


Figure 9.3: Selected Reach for Slope-Area Calculations.

The following calculations were performed to achieve the required flow rate. The calculations are performed for three different sections along the chosen reach, and for three different assumptions of water depths: 1.5, 2.0 and 2.5m:

1) Compute the coefficients $Ku = Au\, Ru^{2/3} / n$
   and $Kd = Ad\, Rd^{2/3} / n$

   Where

   A=Area cross-section
   R=Hydraulic Radius
   u= at upstream section
   d= at downstream section
   n = Manning's coefficient

2) Find the geometric mean of upstream and downstream K:

   $K = (Ku\, Kd)^{0.5}$

3) Estimate the slope S:

   $S = \Delta$ Water Surface Elevation / L

4) Find the flow Q:

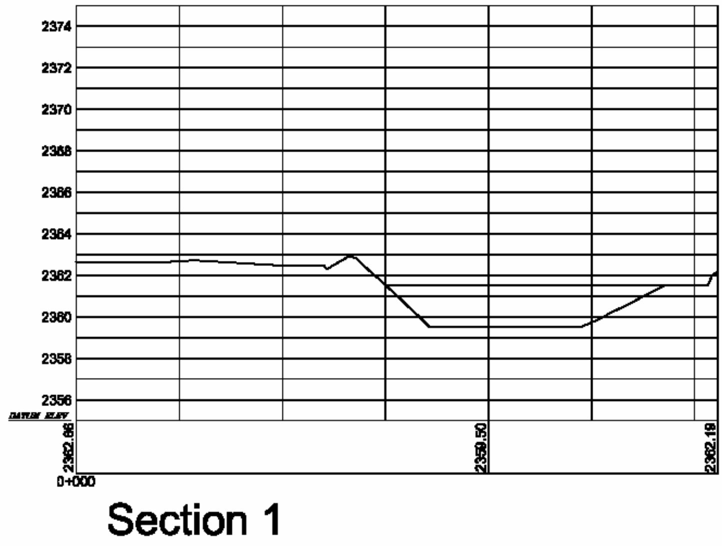
   $Q = K\, S^{0.5}$

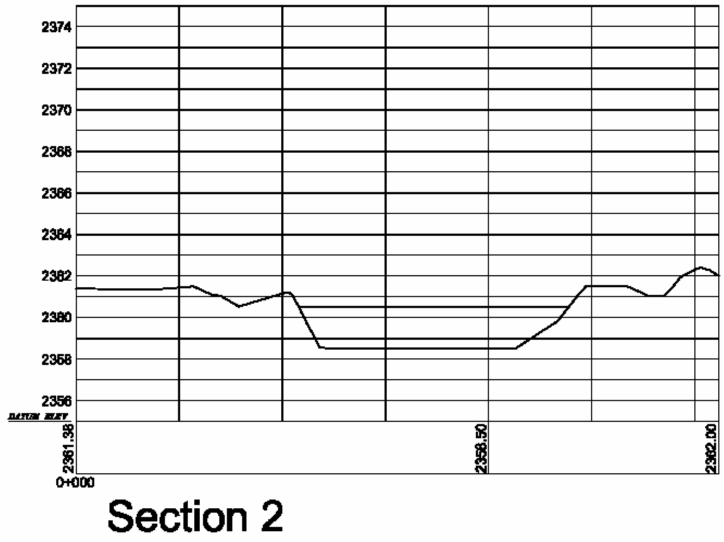
5) Find head velocity upstream and downstream:

6) $h_{vu} = \dfrac{\alpha_u (Q/Au)^2}{2g}$ and $h_{vd} = \dfrac{\alpha_d (Q/Ad)^2}{2g}$ Compute new value of S:

   α = energy coefficient = 1 from uniform velocity distribution.
   $S = h_f / L$

   Where h_f = Water Surface Elevation Difference + $k\,(h_{vu} - h_{vd})$
   $K = 1$ if $Q / Au < Q / Ad$ or = 0.5





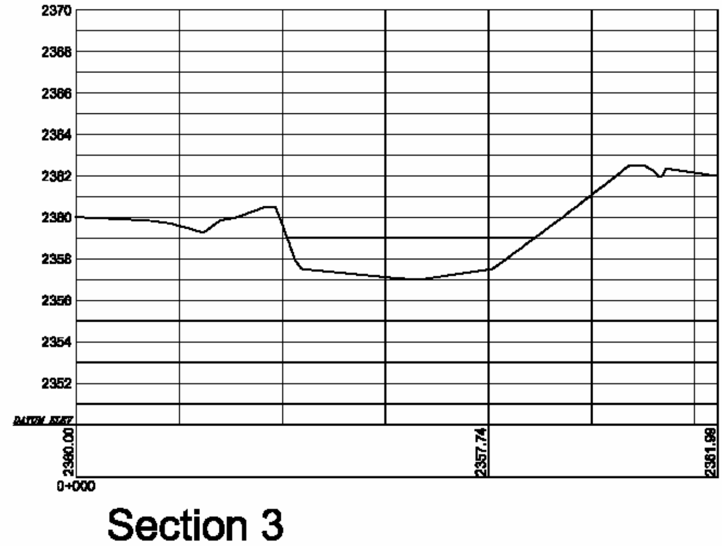


Figure 9.4: Three Cross-Sections along Selected Reach.

7) Use new *S* to find *Q* again and repeat until no change.

After study of the results, the most representative value of flow is chosen to be that which is achieved by finding the average flow of 2m depth, $\boldsymbol{Q_{av} = 118.975\ m^3/s}$. This value is close to the value of the 500-year flood. The velocity was then estimated by determining the cross sectional area of the narrowest section along the wadi. This flow velocity was then used to calculate appropriate rock sizes required for protection of the downstream slope of all the check dams in case of floods, and for prevention of overtopping on the check dam. Results of the flow calculations are summarized in **Table 9.3** below.

Comparing the Q_{500} and the 2m flow computed with the slope-area method, it can be seen that the average flow obtained using the slope-area method is almost equal to the $Q_{500.}$ While the design of such structures could be based on Q_{100}. it was decided to design the check dams using Q_{500}. This allowed the service times of the check dams to increase, and enhanced the stability of the structures.

Particle erosion is a hydraulic phenomenon which tests the riprap material's ability to resist motion against the tractive force exerted by flowing water. Two principal methods or approaches have been historically used to evaluate a material's resistance to particle erosion. These methods are:

1. Permissible velocity approach:
Under the permissible velocity approach, the channel is assumed to be stable if the computed mean velocity is lower than the maximum permissible velocity.

2. Permissible tractive force (shear stress) approach:
The tractive force (boundary shear stress) approach focuses on stresses developed at the interface between flowing water and the material forming the channel boundary. By Chow's definition, permissible tractive force is the maximum unit tractive force that will not cause serious erosion of channel bed material from a level channel bed. Permissible tractive force methods are generally considered to be more academically correct; however, the engineering community more readily embraces critical velocity approaches.

Table 9.3: Flow Calculation Sheet of Slope Area Method.

Bahman Check Dams Project

Slope-Area Method Depth 2m

Section # 1 and # 2			*Section # 2 and # 3*			*Section # 1 and # 3*		
	U/S	**D/S**		**U/S**	**D/S**		**U/S**	**D/S**
Water Level	2361.510	2360.500	**Water Level**	2360.500	2359.000	**Water Level**	2361.510	2359.000
Area	21.000	22.860	**Area**	22.860	18.370	**Area**	21.000	18.370
Wetted P.	16.880	14.980	**Wetted P.**	14.980	13.510	**Wetted P.**	16.880	13.510
R	1.244	1.526	**R**	1.526	1.360	**R**	1.244	1.360
Depth	2.000	2.000	**Depth**	2.000	2.000	**Depth**	2.000	2.000
Top Width	15.600	13.090	**Top Width**	13.090	11.990	**Top Width**	15.600	11.990
DisBetSec	75.000		**DisBetSec**	75.000		**DisBetSec**	150.000	
WSSlope	0.013		**WSSlope**	0.020		**WSSlope**	0.017	
n	0.025	0.025	**n**	0.025	0.025	**n**	0.025	0.025
$K_{u\&d}$	971.6514901	1212.027552	**$K_{u\&d}$**	1212.027552	901.8583954	**$K_{u\&d}$**	971.6514901	901.8583954
K	1085.204302		**K**	1045.503335		**K**	936.1047237	
Q_P	125.902		**Q_P**	147.856		**Q_P**	121.080	
h_v	1.832	1.546	**h_v**	2.132	3.302	**h_v**	1.694	2.214
k	0.5		**k**	1		**k**	1	
h_f	1.152		**h_f**	0.330		**h_f**	1.990	
S	0.015		**S**	0.004		**S**	0.013	
Q_P	134.524		**Q_P**	69.383		**Q_P**	107.811	
h_v	2.092	1.765	**h_v**	0.470	0.727	**h_v**	1.343	1.756
k	0.5		**k**	1		**k**	1	
h_f	1.173		**h_f**	1.242		**h_f**	2.097	
S	0.016		**S**	0.017		**S**	0.014	
Q_P	135.895		**Q_P**	110.830		**Q_P**	110.202	
h_v	2.134	1.801	**h_v**	1.198	1.855	**h_v**	1.404	1.834
k	0.5		**k**	1		**k**	1	
h_f	1.176		**h_f**	0.843		**h_f**	2.079	
S	0.016		**S**	0.011		**S**	0.014	
Q_P	135.895	0.000	**Q_P**	110.830	0.000	**Q_P**	110.202	0.000
Peak Flow	***135.895***	***m^3/s***	***Peak Flow***	***110.830***	***m^3/s***	***Peak Flow***	***110.202***	***m^3/s***
Set the value equal to the former Q_P					*Goal Seek C32 = 0 by changing B27*			

The tractive force (boundary shear stress) approach focuses on stresses developed at the interface between the flowing water and the material forming the channel boundary. By Chow's definition, permissible tractive force is the maximum unit tractive force that will not cause serious erosion of channel bed material from a level channel bed. The basic premise underlying riprap design based on tractive force theory is that the flow-induced tractive force should not exceed the permissible stress or critical shear stress of the riprap. The following formula (used in HEC 11) can be used to calculate D_{50}:

$$D_{50} = \frac{0.00594 V_{av}^{\ 3}}{K_l^{\ 1.5} \sqrt{d_{av}}}$$

Where

- D_{50} = the median riprap particle size (m);
- V_{av} = the average velocity in the main channel (m/s);
- d_{av} = the average flow depth in the main flow channel (m); and

K_l is defined as:

$$K_l = (1 - \frac{\sin^2 \theta}{\sin^2 \phi})^{0.5}$$

Where

- θ = the bed angle with the horizontal (18.43^o); and
- ϕ = the riprap material's angle of repose (35^o).

The average flow depth and velocity used in the above equation are main channel values. The main channel is defined as the area between the channel banks. The velocity was considered to be 2/3 of the flowing velocity, as the flow is parallel with no bends and impinges.

Raudkivi (1976) in "Loose Boundary Hydraulics" presents another formula for this computation. In principle, we could calculate the size of stones that would be at the point of movement by combining the Strickler and Manning formulae:

$$V = 5.88(S_S - 1) D_{60}^{\frac{1}{3}} y_o^{\ 1/6}$$

where;

- V = Flow velocity (m/s)
- S_S = Riprap specific gravity (2.65)
- D_{60} = Riprap size for 60% finer (m)
- y_o = Flow depth (m)

The riprap should be composed of a well-graded mixture where about 60% of the stones should be equal to or larger than that given by the above formula. The stones must also not be flat. It is a sound practice to place riprap on top of a graded gravel filter. This filter prevents the washing out of fines from the subgrade, and it prevents the collapse of riprap.

Abt, Johnson, Thornton, and Trabant (1998) present another formula for sizing stones in "Riprap Sizing at Toe of Embankment Slope". The median stone size identified in this equation is designed to resist stone movement on embankment slopes:

$$D_{50} = 50.74 S^{0.43} q^{0.56}$$

where;

D_{50} = Riprap size 50% finer (cm)
S = Bed slope
q = Specific flow rate (m^3/s per m width)

Finally, the California Bank and Shore Rock Slope Protection Design provides a formula for determining minimum rock size. This is accomplished by solving the following equation *W* in US customary units. To get values in System International (SI), metric units, first divide the weight of minimum stable rock, *W* in pounds by 2.2 to get *W* in kilograms, then divide by 1000 to get *W* in tones. Use *W* later to find $D_{\min}$ (minimum rock size).

$$W = \frac{0.00002 V^6 S_S}{(S_S - 1)^3 \sin^3(70 - \theta)}$$

where;

W = theoretical minimum rock mass (size or weight) which resists forces of flowing water and remains stable on slope of stream or river, lb.
V = velocity to which section is exposed, ft/s:
- for PARALLEL flow multiply average channel velocity by 0.67 (2/3)
- for IMPINGING flow multiply average channel velocity VM by 1.33 (4/3)

S_S = specific gravity of the rock (2.65).
θ = outside slope face angle with horizontal.

To find $D_{\min}$:

$$W(tonnes) = \gamma_S \frac{\pi}{6} D_{\min}^3 (m)$$

where *W* is in tonnes and *D* in meters.

Summary of the results obtained using the four different equations are summarized in **Figure 9.5** and **Table 9.4** below. Other calculation trials for impinging flow and maximum flows were explored, and engineering judgment was used to select the most applicable rock size depending on the construction feasibility. **Table 9.4** presents technically feasible rock sizes for the check dams at Bahman. The calculation sheets for other trials are kept at the end of this section for reference.

Table 9.4: Rock Size and Weight Design Values.

	D (mm)	**W (tonnes)**
Minimum Size	350.00	0.06
D50	450.00	0.13
D60	750.00	0.59
Maximum Size (Types 1 & 2)	1100.00	1.85
Maximum Size (Types 3 & 4)	850.00	0.85

All stones should be contained reasonably well within the riprap layer thickness in order to provide maximum resistance against erosion. Therefore, smaller size rip-rap was selected for check dam Types 3 and 4, which are of lower crest height than Types 1 and 2. The crest height of Types 1 and 2 check dams is 2m and 3m, respectively, while the crest height of check dam Types 3 and 4 is 1.5m and 1m, respectively. These types are as shown in **Figure 9.**1.

Oversize stones, even in isolated spots, may cause riprap failure in several ways. They may preclude mutual support between individual stones; provide large voids that expose filter and bedding materials; and create excessive local turbulence that removes smaller stones. Small amounts of oversize stones should be removed individually and replaced with proper size stones. The following criteria apply to the riprap layer thickness, as described along with **Table 9.5, 9.6** and **9.7.**

- Riprap should not be less than the spherical diameter of the D_{100} (W_{100}) stone, or less than 1.5 times the spherical diameter of the D_{50} (W_{50}) stone, whichever results in the greater thickness.
- It should not be less than 300 mm for practical placement.
- The thickness determined by either 1) or 2) should be increased by 50 percent when the riprap is placed underwater to provide for uncertainties associated with this type of placement.
- An increase in thickness of 150-300 mm, accompanied by an appropriate increase in stone sizes, should be provided where riprap revetment will be subject to attack by floating debris or by waves from boat wakes, wind, or bedforms.

Results of the Slope-Area Analysis

	1.500	2.000	2.500
Q_{max}	86.893	135.895	198.545
Q_{av}	74.162	118.975	175.075

Average Q **Parallel Flow**

Characteristics of the Narrowest Cross-Section along the wadi

	1.500	2.000	2.500
Area	8.250	12.140	16.390
Top Width	7.440	8.140	8.840
Av. Velocity	8.989	9.800	10.682
2/3 Velocity	5.993	6.534	7.121

Rock Sizing

		1.50		2.00		2.50	
		D (mm)	Weight (tons)	D (mm)	Weight (tons)	D (mm)	Weight (tons)
Equation 1	D_{50}	1369.63	3.56	1536.96	5.04	1780.05	7.83
Equation 2	D_{60}	649.46	0.38	728.81	0.54	844.08	0.83
Equation 3	D_{50}	341.99	0.06	423.74	0.11	502.33	0.18
Equation 4	D_{min}	774.06	0.64	920.01	1.08	1092.97	1.81

Equation 1

$$D_{50} = \frac{0.00594 V_{av}^{3}}{K_l^{1.5}\sqrt{d_{av}}}$$

$$K_l = \left(1 - \frac{\sin^2\theta}{\sin^2\phi}\right)^{0.5}$$

	Degrees	Radians	Sin
θ	18.43	0.321664	0.316145824
Φ	35	0.610865	0.573576436
K_l		0.834384	

Design Values

	D (mm)	W (tonnes)
Minimum Size	350.00	0.06
D50	450.00	0.13
D60	750.00	0.59
Maximum Size	1100.00	1.85

Calculations for Equation 4

	Degrees	Radians	
(70-θ)	51.57	0.90	
Sin (70-θ)		0.78	
	1.5	2.00	2.50
$W_{(lb)}$	1415.77	2377.12	3985.63
$W_{(kg)}$	643.53	1080.51	1811.65
$W_{(tons)}$	0.64	1.08	1.81

Equation 2

$$V = 5.88(S_S - 1) D_{60}^{\frac{1}{3}} y_o^{1/6}$$

Equation 3

$$D_{50(cm)} = 50.74\, S^{0.43} q^{0.56}$$

S= 0.02

Equation 4

$$W_{(lb)} = \frac{0.00002 V_{(ft/s)}^{6} S_s}{(S_s - 1)^3 \sin^3(70 - \theta)}$$

$$W_{(tons)} = \gamma_S \frac{\pi}{6} D^3_{\min(m)}$$

Figure 9.5: Rock Sizing Calculation Sheet.

Table 9.5: Guide for Determining Rock Class of Outside Layer (Design of Riprap Revetment HEC 11).

GRADING OF ROCK SLOPE PROTECTION **PERCENTAGE LARGER THAN**

STANDARD Rock SIZE or Rock MASS or Rock WEIGHT		RSP-Classes [A]											
		Method A Placement					Method B Placement						
		RSP-Classes other than Backing									Backing No.		
US unit		8 ton	4 ton	2 ton	1 ton	1/2 ton	1 ton	1/2 ton	1/4 ton	Light	1 [B]	2	3
	SI unit	8 T	4 T	2 T	1 T	1/2 T	1 T	1/2 T	1/4 T	Light	1 [B]	2	3
16 ton	14.5 tonne	0-5											
8 ton	7.25 tonne	50-100	0-5										
4 ton	3.6 tonne	95-100	50-100	0-5									
2 ton	1.8 tonne		95-100	50-100	0-5		0-5						
1 ton	900 kg			95-100	50-100	0-5	50-100	0-5					
1/2 ton	450 kg				95-100	50-100	-----	50-100	0-5				
1/4 ton	220 kg					95-100	95-100	-----	50-100	0-5			
200 lb	90 kg							95-100	-----	50-100	0-5		
75 lb	34 kg								95-100	-----	50-100	0-5	
25 lb	11 kg									95-100	90-100	25-75	0-5
5 lb	2.2 kg											90-100	25-75
1 lb	0.4 kg												90-100

[A] US customary names (units) of RSP-Classes listed above SI names, example US is "2 ton" metric is "2 T".
[B] "Facing" has same gradation as "Backing No. 1". To conserve space "Facing" is not shown .

Example for determining RSP-Class of outside layer. By using Equation 1, if the calculated W=135 kg (minimum stable rock size):
1. Enter table at left and select closest value of STANDARD Rock SIZE which is greater than calculated W, in this case 220 kg
2. Trace to right and locate "50-100" entry 3. Trace upward and read column heading "1/4 T", then 1/4 T is first trial RSP-Class.

Table 9.6: Layered Rock Slope Protection (California Bank and Shore Rock Slope Protection Design, 3rd Ed. Internet 2000).

SI metric (US customary values shown for OUTSIDE LAYER only)			
OUTSIDE LAYER RSP-CLASS *	INNER LAYERS RSP-CLASS *	BACKING CLASS No. *	RSP-FABRIC TYPE **
8 T (8 ton)	2 T over 1/2 T	1	B
8 T (8 ton)	1 T over 1/4 T	1 or 2	B
4 T (4 ton)	1/2 T	1	B
4 T (4 ton)	1 T over 1/4 T	1 or 2	B
2 T (2 ton)	1/2 T	1	B
2 T (2 ton)	1/4 T	1 or 2	B
1 T (1 ton)	LIGHT	NONE	B
1 T (1 ton)	1/4 T	1 or 2	B
1/2 T (1/2 ton)	NONE	1	B
1/4 T (1/4 ton)	NONE	1 or 2	A
LIGHT (LIGHT)	NONE	NONE	A
Backing No. 1*** (Backing No. 1)	NONE	NONE	A

* Rock grading and quality requirements per Section 72-2.02 Materials of the Caltrans *Standard Specificati* x B).

** RSP-fabric Type of geotextile and quality requirements per Section 88-1.04 Rock Slope Protection Fabric of the Caltrans *Standard Specificati* x B). Type A RSP-fabric has lighter mass per unit area and it also has lower toughness (tensile x elongation, both at break) than Type B RSP-fabric. Both types require minimum permittivity of 0.5 per second.

*** "Facing" RSP-Class has same gradation as Backing No. 1.

Table 9.7: Minimum Layer Thickness (California Bank and Shore Rock Slope Protection Design, 3rd Ed. Internet 2000).

SI metric (US customary)		
RSP-Class Layer	Method of Placement	Minimum Thickness
8 T (8 ton)	A	2.60 meters (8.5 feet)
4 T (4 ton)	A	2.07 meters (6.8 feet)
2 T (2 ton)	A	1.65 meters (5.4 feet)
1 T (1 ton)	A	1.31 meters (4.3 feet)
1/2 T (1/2 ton)	A	1.04 meters (3.4 feet)
1 T (1 ton)	B	1.65 meters (5.4 feet)
1/2 T (1/2 ton)	B	1.31 meters (4.3 feet)
1/4 T (1/4 ton)	B	1.00 meters (3.3 feet)
Light	B	760 millimeters (2.5 feet)
Facing	B	550 millimeters (1.8 feet)
Backing No. 1	B	550 millimeters (1.8 feet)
Backing No. 2	B	380 millimeters (1.25 feet)
Backing No. 3	B	230 millimeters (0.75 feet)

From the above tables, the following information with regards to the layering and method of placement can be summarized in **Figure 9.6** and **Table 9.8**.

Table 9.8: Summary of Rock Size Results.

	D (mm)	**W (tonnes)**	**Minimum Layer Thickness**	**Method of Placement**	**Proposed Passing Envelope %**
Minimum Size (For Stability)	350.00	0.06	Graded 1.31m	B	0-20
D50	450.00	0.13		B	20-50
D60	750.00	0.59		B	50-70
Maximum Size (Outer Layers for Dam Types 1&2)	1100.00	1.85	1.1m	A	70-100
Maximum Size (Outer Layers for Dam Types 3&4)	850.00	0.85	0.85m	A	70-100

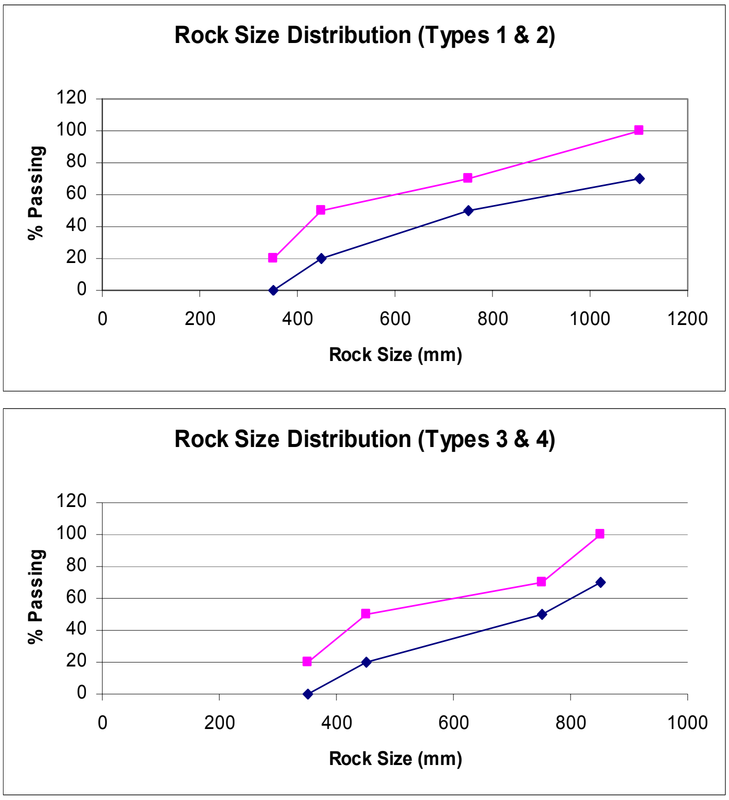


Figure 9.6: Rock Size Envelope.

The Method of Placement "A" is used for large Rock Slope Protection (RSP) Classes, which require individual placement by equipment to achieve '3-point bearing' (no wobbling) on adjacent rocks. Method B, also called 'dumped RSP,' does not mean that the rock can be dumped from the top to the bottom of long embankments. Placing rock by Method B means that rock is dumped near its planned location. After this step is complete, machinery pushes the rocks to their final position. **Figure 9.7** presents the layers and rock sizes.

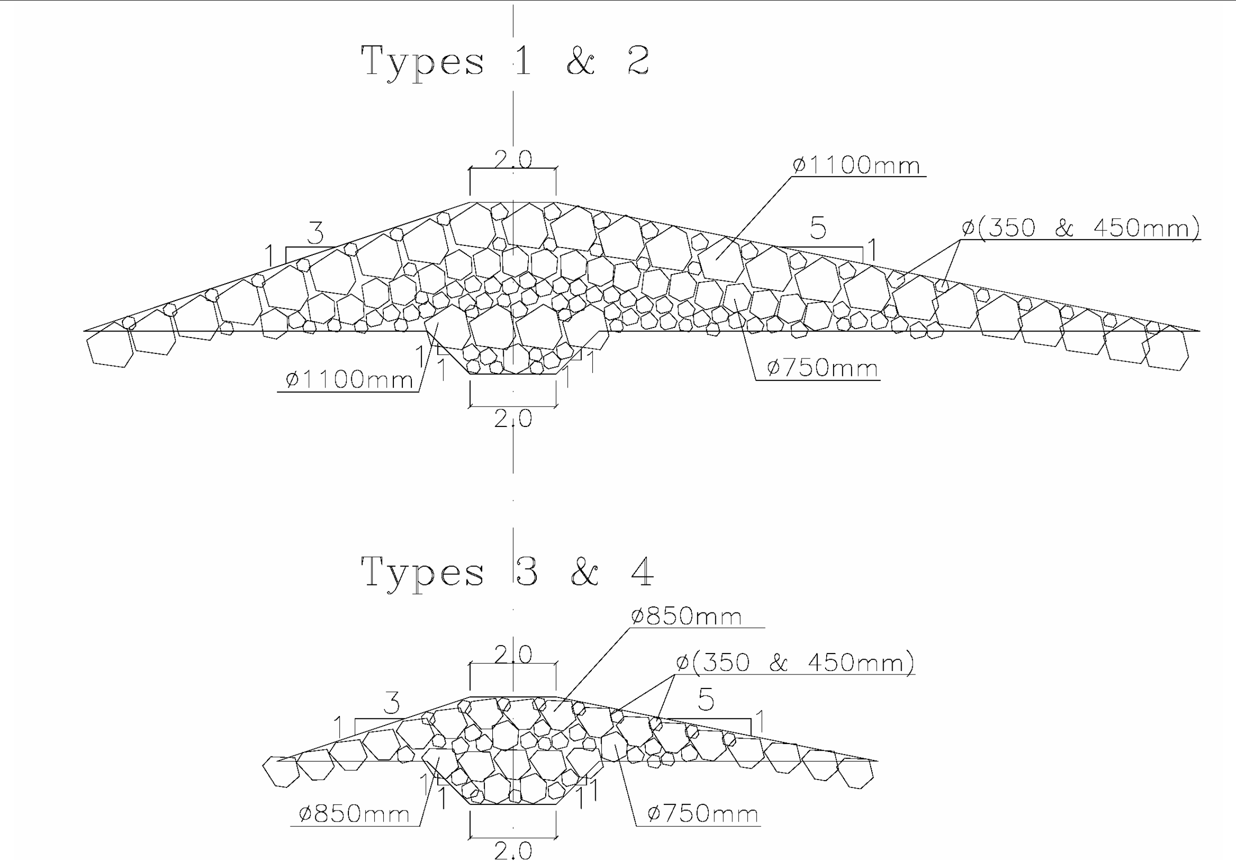


Figure 9.7: Check Dam Rock Layering.

9.4 Instrumentation

The instrumentation required for monitoring Wadi Bahman is listed below:

- 27 Piezometers
- Parshall Flume and Runoff Recorder

A Piezometer is installed just upstream of each of the 27 check dams, as shown in **Figure 9.8,** for the purposes of monitoring the depth of subsurface water within the alluvium strata. Each piezometer is composed of a 15 m long standpipe, with perforated and solid PVC pipe of 50mm in diameter. The perforated section of the pipe is packed with envelope filter, and the top of the pipe is protected by a concrete slab with steel cover and padlock as shown in **Figure 9.9**.

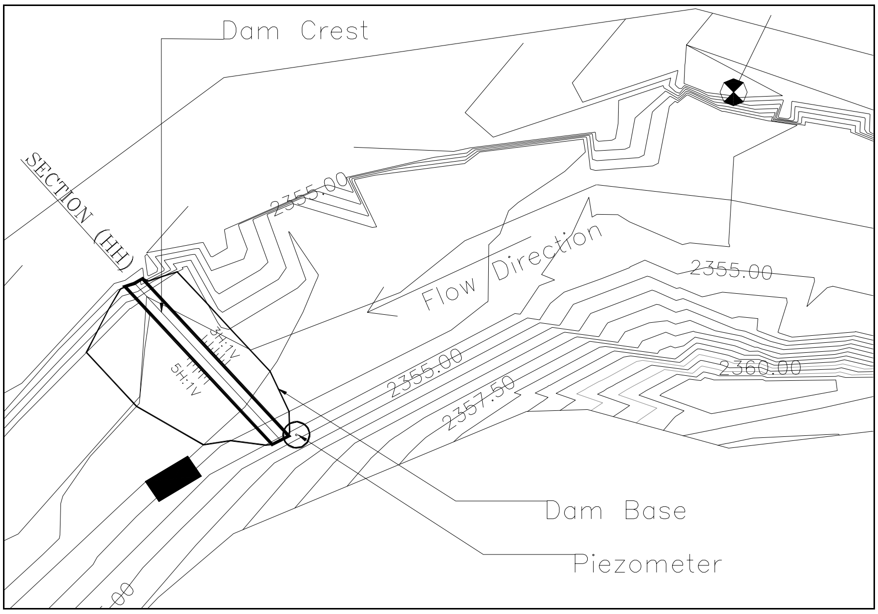


Figure 9.8: Typical Piezometer Location.

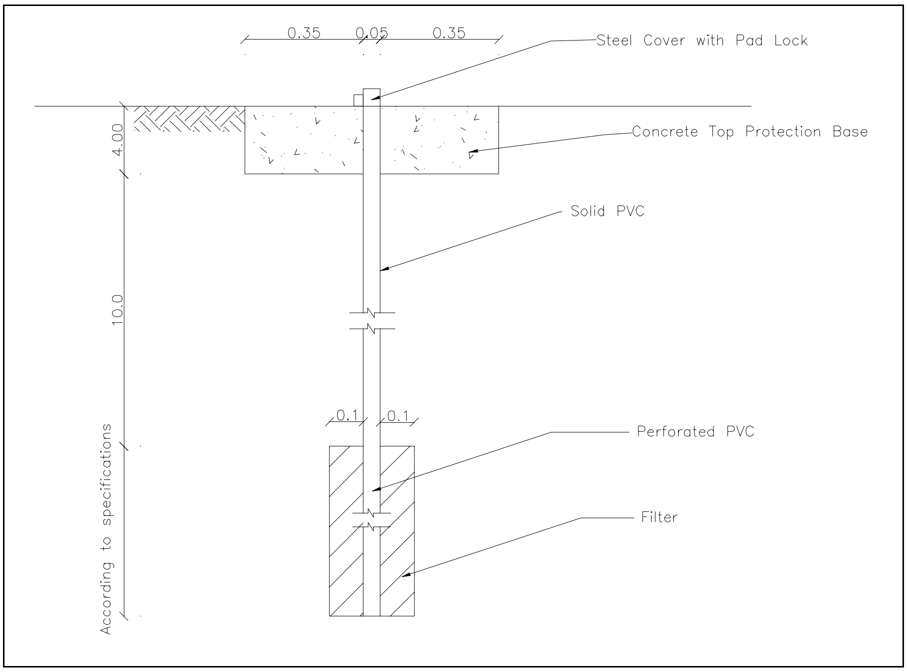


Figure 9.9: Piezometer Detail.

The water flowing in a wadi usually contains suspended sediments. If a weir is used to measure the flow in the wadi, some of the sediments will be deposited in the pool above the weir. This will result in a gradual change in the weir coefficient, and therefore, errors in the measurements. Moreover, the use of a weir results in a relatively large head loss. Both these difficulties are partially overcome by use of Venturi-type flumes. For purposes of measuring runoff and flood flow in the wadi, the most common type of these flumes, the Parshall Flume, was selected for use. A runoff recorder will be installed to measure the runoff passing through the flume. **Figure 9.10** shows the proposed locations of the Parshall flume and runoff recorder, while **Figure 9.11** shows the details of the Parshall flume.

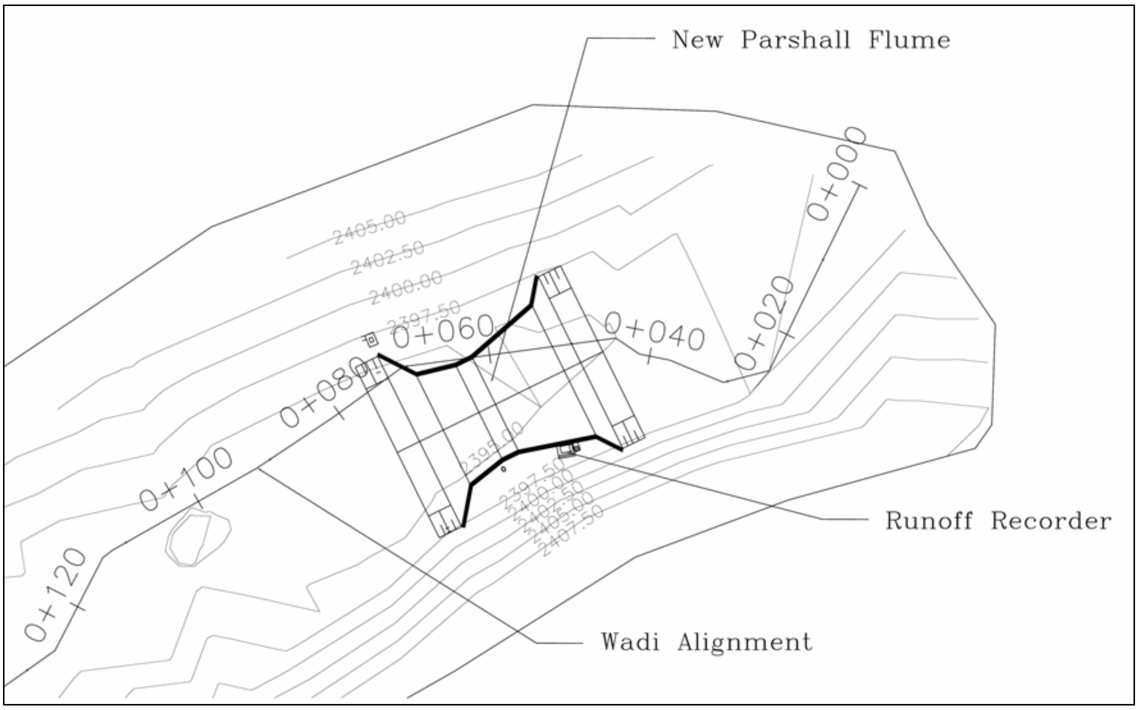


Figure 9.10 Parshall Flume Location.

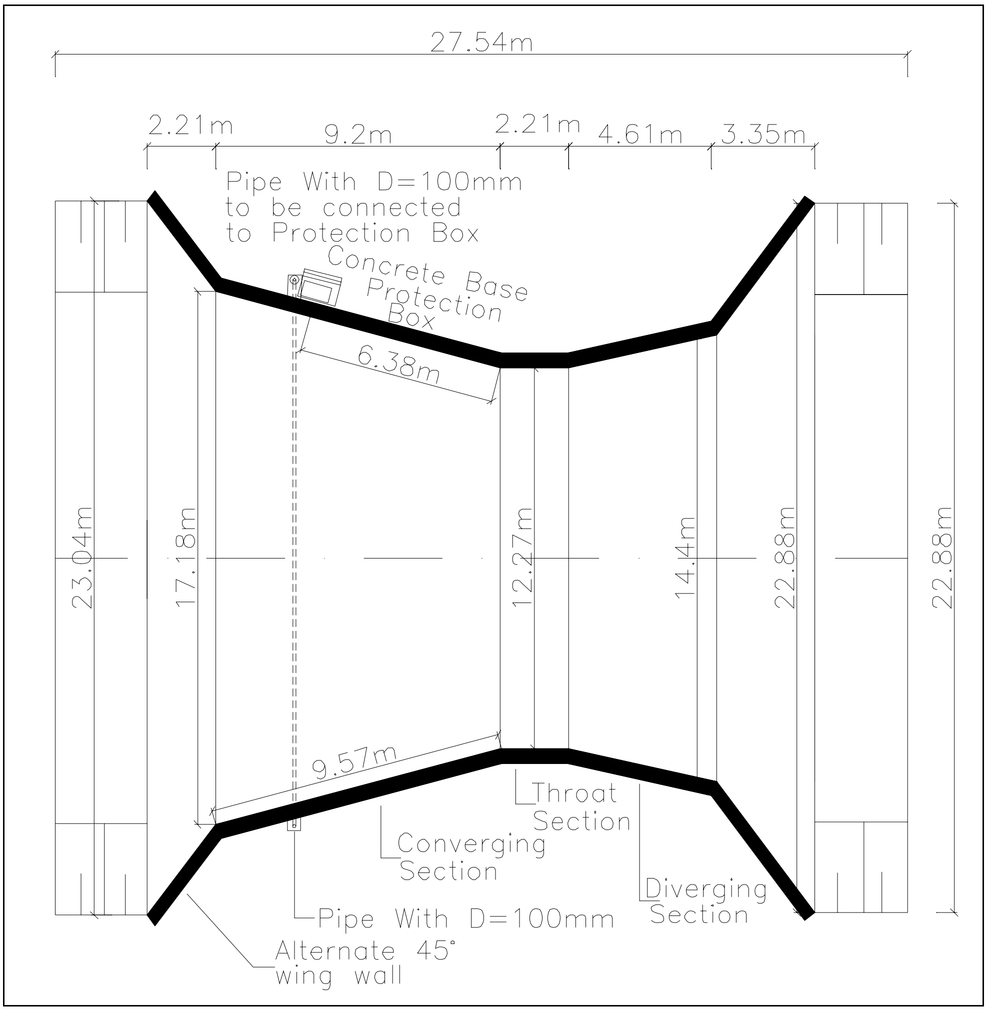


Figure 9.11 Parshall Flume Details.

CALCULATION SHEETS FOR OTHER TRIALS (ROCK SIZING)

Results of the Slope-Area Analysis

	1.500	2.000	2.500
Q_{max}	86.893	135.895	198.545
Q_{av}	74.162	118.975	175.075

Average Q **Impinging Flow**

Characteristics of the Narrowest Cross-Section along the wadi			
	1.500	2.000	2.500
Area	8.250	12.140	16.390
Top Width	7.440	8.140	8.840
Av. Velocity	8.989	9.800	10.682
4/3 Velocity	11.986	13.067	14.242

		1.50		2.00		2.50	
		D (mm)	Weight (tons)	D (mm)	Weight (tons)	D (mm)	Weight (tons)
Equation 1	D_{50}	9167.21	**1068.95**	10287.22	**1510.56**	11914.23	**2346.62**
Equation 2	D_{60}	649.46	**0.38**	728.81	**0.54**	844.08	**0.83**
Equation 3	D_{50}	341.99	**0.06**	423.74	**0.11**	502.33	**0.18**
Equation 4	D_{min}	2838.93	**31.75**	3374.24	**53.31**	4008.58	**89.38**

Equation 1

$$D_{50} = \frac{0.00594 V_{av}^{3}}{K_l^{1.5}\sqrt{d_{av}}}$$

$$K_l = (1 - \frac{\sin^2\theta}{\sin^2\phi})^{0.5}$$

	Degrees	Radians	Sin
θ	11.31	0.197396	0.196116135
Φ	35	0.610865	0.573576436
K_l		0.93973	

Calculations for Equation 4

	Degrees	Radians
(70-θ)	58.69007	1.02
Sin (70-θ)		0.85

	1.5	2.00	2.50
$W_{(lb)}$	69844.61	117271.69	196625.14
$W_{(kg)}$	31747.55	53305.31	89375.06
$W_{(tons)}$	31.75	53.31	89.38

Equation 2

$$V = 5.88(S_S - 1) D_{60}^{\frac{1}{3}} y_o^{1/6}$$

Equation 3

$$D_{50\,(cm)} = 50.74\, S^{0.43} q^{0.56}$$

S= 0.02

Equation 4

$$W_{(lb)} = \frac{0.00002 V_{(ft/s)}^{6} S_s}{(S_s - 1)^3 \sin^3(70 - \theta)}$$

$$W_{(tons)} = \gamma_S \frac{\pi}{6} D_{\min(m)}^3$$

Results of the Slope-Area Analysis

	1.500	2.000	2.500
Q_{max}	86.893	135.895	198.545
Q_{av}	74.162	118.975	175.075

Max Q **Parallel Flow**

Characteristics of the Narrowest Cross-Section along the wadi			
	1.500	2.000	2.500
Area	8.250	12.140	16.390
Top Width	7.440	8.140	8.840
Av. Velocity	10.533	11.194	12.114
2/3 Velocity	7.022	7.463	8.076

		1.50		2.00		2.50	
		D (mm)	Weight (tons)	D (mm)	Weight (tons)	D (mm)	Weight (tons)
Equation 1	D_{50}	1843.15	**8.69**	1916.22	**9.76**	2172.08	**14.22**
Equation 2	D_{60}	1044.64	**1.58**	1086.06	**1.78**	1231.07	**2.59**
Equation 3	D_{50}	373.72	**0.07**	456.50	**0.13**	538.99	**0.22**
Equation 4	D_{min}	974.32	**1.28**	1100.54	**1.85**	1288.84	**2.97**

Equation 1
$$D_{50} = \frac{0.00594 V_{av}^{3}}{K_l^{1.5}\sqrt{d_{av}}}$$

$$K_l = (1 - \frac{\sin^2\theta}{\sin^2\phi})^{0.5}$$

	Degrees	Radians	Sin
θ	11.31	0.197396	0.196116135
Φ	35.00	0.610865	0.573576436
K_l		0.93973	

Equation 2
$$V = 5.88(S_S - 1) D_{60}^{\frac{1}{3}} y_o^{1/6}$$

Equation 3
$$D_{50(cm)} = 50.74 S^{0.43} q^{0.56}$$

S= 0.02

Equation 4
$$W_{(lb)} = \frac{0.00002 V_{(ft/s)}^{6} S_s}{(S_s - 1)^3 \sin^3(70-\theta)}$$

$$W_{(tons)} = \gamma_S \frac{\pi}{6} D^3_{\min(m)}$$

Calculations for Equation4

	Degrees	Radians	
(70-θ)	58.69007	1.02	
Sin (70-θ)		0.85	
	1.5	2.00	2.50
$W_{(lb)}$	2823.44	4068.99	6535.21
$W_{(kg)}$	1283.38	1849.54	2970.55
$W_{(tons)}$	1.28	1.85	2.97

Results of the Slope-Area Analysis

	1.500	2.000	2.500
Q_{max}	86.893	135.895	198.545
Q_{av}	74.162	118.975	175.075

Max Q **Impinging Flow**

Characteristics of the Narrowest Cross-Section along the wadi

	1.500	2.000	2.500
Area	8.250	12.140	16.390
Top Width	7.440	8.140	8.840
Av. Velocity	10.533	11.194	12.114
4/3 Velocity	14.043	14.925	16.152

		1.50		2.00		2.50	
		D (mm)	Weight (tons)	D (mm)	Weight (tons)	D (mm)	Weight (tons)
Equation 1	D_{50}	14745.17	**4448.30**	15329.74	**4998.60**	17376.66	**7280.20**
Equation 2	D_{60}	1044.64	**1.58**	1086.06	**1.78**	1231.07	**2.59**
Equation 3	D_{50}	373.72	**0.07**	456.50	**0.13**	538.99	**0.22**
Equation 4	D_{min}	3897.30	**82.14**	4402.17	**118.37**	5155.34	**190.12**

Equation 1
$$D_{50} = \frac{0.00594 V_{av}^{3}}{K_l^{1.5}\sqrt{d_{av}}}$$

$$K_l = (1 - \frac{\sin^2\theta}{\sin^2\phi})^{0.5}$$

	Degrees	Radians	Sin
θ	11.31	0.197396	0.196116135
Φ	35	0.610865	0.573576436
K_l		0.93973	

Calculations for Equation4

	Degrees	Radians
(70-θ)	58.690068	1.02
Sin (70-θ)		0.85

	1.5	2.00	2.50
$W_{(lb)}$	180699.85	260415.34	418253.58
$W_{(kg)}$	82136.30	118370.61	190115.26
$W_{(tons)}$	82.14	118.37	190.12

Equation 2
$$V = 5.88(S_S - 1)D_{60}^{\frac{1}{3}} y_o^{1/6}$$

Equation 3
$$D_{50(cm)} = 50.74\, S^{0.43} q^{0.56}$$

S= 0.02

Equation 4
$$W_{(lb)} = \frac{0.00002 V_{(ft/s)}^{6} S_s}{(S_s - 1)^3 \sin^3(70-\theta)}$$

$$W_{(tons)} = \gamma_S \frac{\pi}{6} D^3_{\min(m)}$$

SECTION TEN: ENVIRONMENTAL ISSUES

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Tables

10.1 Yemen Overview

10.1.1 Introduction

The Republic of Yemen is located in the south and south eastern part of the Arabian Peninsula and the country is surrounded from the west and south by the Red and the Arabian Seas and to the east and north it is bordered by Sultanate of Oman and the Kingdom of Saudi Arabia. The present Republic of Yemen was born in 1990, as a result unification of the former Yemen Arab Republic and the People's Democratic Republic of Yemen.

Yemen is a mountainous country with an area of 454,000 square kilometers and has a population of roughly 20 million people. The terrain comprises of narrow coastal plain backed by flat topped hills and rugged mountains; dissected upland desert plains in central Yemen that slope into the desert interior of the Arabian Peninsula. With a scarce natural resources and largely unrealized human capacity, Yemen is among the poorest countries in the world, having a gross national income per capita of only US$ 510. The natural resources mainly comprise petroleum, fish, rock, salt, marble, small deposits of coal, copper, lead, nickel and gold. The major industrial sectors are crude oil production and petroleum refining, small scale production of textiles and leather goods, food processing, handicrafts and cement.

10.1.2 Agriculture and Economy

Agriculture is a significant sector of the economy, accounting for about 11 percent of the country's gross domestic product (GDP) and employing more than 50 percent of the rural population. Currently, an estimated 73% of the population lives in the rural areas. Agriculture is characterized by low and uncertain crop yields due to drought, insufficient and erratic rainfall, declining soil productivity due to soil erosion and poor crop management, and crop losses due to damage by insects and diseases.

The major agricultural products are fruits like mango, grape, citrus banana, papaya and date, vegetables include tomatoes, potatoes, watermelon, onion and cucumber; cereals include maize, wheat, sorghum and barely and commercial crops like qat. In addition to agriculture, oil is a major sector which contributes to the Yemeni economy.

The northern city Sana'a is the political capital of the Republic of Yemen, and the southern city Aden, with its refinery and port facilities, is the economic and commercial capital. The low level of domestic industry and agriculture has made northern Yemen dependent on imports for practically all of its essential needs. Once self sufficient in food production, northern Yemen has become a major importer. Land once used for export crops like cotton, fruits and vegetables, has been turned to growing qat shrubs which have no significant export market.

10.1.3 Climate and Water Resources

The climate of Yemen is mostly desert climate with a hot and humid climate along the west coast; the temperate in the western mountains affected by the seasonal monsoons and extraordinary hot desert in the east. The country is facing problems like limited natural fresh water sources, inadequate supplies of potable water, over grazing, soil erosion, and desertification. Only 2.75 percent of the country is considered to be arable land.

Rain fall is the major source of all water to the country. During the last decades, Yemen is facing the pressing problem of providing water demands for the growing population. The agricultural sector is by far the major consumer of water and will continue to be in the future. The pressing need to increase agricultural products, people's domestic needs and industrial uses has lead to the available water resources depletion. In general, all surface water sources in Yemen are harnessed and exploited.

Increasing water demand in the recent years and the limited availability of surface water resources has increased the pressure on the available sources, mostly non-renewable, ground water resources. The ground water withdrawals for agricultural purposes exceed the annual ground water recharge. The rate of decline of the ground water levels is alarmingly high in many zones, especially in the Yemen highlands, where decline of between 2 and 6 m/year is commonly observed. In coastal zones this leads to the incidence of salt water intrusion. Spring fed irrigation has reduced significantly as ground water tables have dropped.

Due to the lack of government controls on resources, population pressure and predominant focus on the tube well irrigation expansion, the delicate balance between land and water resources is being endangered.

10.2 Project

10.2.1 Background

The Sana'a basin is located in the central highlands and covers approximately 3,200 square kilometers, ranging from 2,000 meters to more than 3,200 meters above sea level. The climate of the Sana'a basin area is characterized by a low and erratic rain fall pattern. The principal source of water in the region is groundwater from three aquifer layers, namely alluvial deposits, volcanic units and Tawilah sandstone.

The rapid urbanization, increased population, and sharp increase in agriculture led to excessive exploitation of the ground water. Agriculture consumes 80% of water in the basin area.

The Sana'a Basin Water Management Project was conceived by the Government of Yemen and the World Bank with a focus to overcome the pressures of water supply shortage within the Sana'a water basin. The main objective is to seek solution for sustainable water management in Sana'a Water Basin. This project would bring about considerable improvement in the quantity and quality of the ground water and would increase efficiency in agriculture and would bring about less water based rural economy in the basin.

Yemen is among the oldest countries in the world where land and water resource practices have been well developed. Terrace erection, rain water harvesting and dam irrigation techniques are well developed in the country.

Dams and reservoirs have contributed significantly to poverty alleviation and improving the quality of life for rural populations. Small dams existed in the history of Yemen, as means of improving the water control, and improving the ground water recharge. Small dams will improve the ground water infiltration and also provide substantial storage.

10.2.2 Objectives

The project objective is to prepare detailed designs and tender documents of the work in the construction of new dams and the possible rehabilitation of three existing dams. The present report will address environmental impacts caused by the proposed dams as per the Section 4.6 of Terms of Reference. The terms of reference are given below:

- Provide the needed information to the team charged with the preparation of Environmental Impact Assessment (EIA). Relevant environmental information required from the study is listed as follows:

- Outline the positive and negative impacts of the project and include a basic analysis of possible alternative sites, technologies, configuration of project components, construction techniques, operating and maintenance procedures including a "no action plan". Such possible alternative project sites where appropriate should be compared in a quantitative and qualitative manner in terms of potential environmental impacts.

- Where possible, compare alternative sites in terms of capital operating costs, suitability under local conditions and the institutional, training and monitoring requirements. This exercise will identify the marginal benefits and possible adverse impacts of each component of the project. Identify alternative solutions, if any, for achieving the same objectives with out resorting of each component of the project. Alternatives for achieving the same objectives without resorting to construction of dams or other structures should be compared.

- It may be possible that some of the physical components of the proposed project, dams etc., could have an impact on sites of archeological or architectural significance. These sites may also include special habitations, forts, towers, cisterns, mosques and burial grounds etc. Identify these potential impacts during the study and refer them to the Cultural Heritage specialist for inspection. Identify potential impacts on health, flora and fauna and refer them to the Health Specialist and Biodiversity Specialist, respectively, for inspection.

- Create a matrix summarizing the analysis of technical alternatives (including no action), environmental benefits and adverse impacts and cost estimates for various alternatives.

10.3 Review

10.3.1 Introduction

There are several studies that were carried out for the Sana'a basin by various consultants, educational institutions and the funding agencies. The feasibility study for this project was carried out by Hydrosult. They made an environmental reconnaissance for all the project sites considering the potential sites from the physical, ecological and socio-economic points of view. Also included in the study was a description of the legislative, regulatory and institutional frame work of Yemen covering the environmental quality, public health and protection of sensitive areas, endangered species, land use control and others.

10.3.2 Review of Hydrosult Feasibility Studies

The six feasibility studies and environmental reconnaissance survey completed by Hydrosult in 2002 were carefully reviewed. In these studies, the scoping proposed was used as a tool for decision making while selecting the alternative project sites. The study led to the prediction and evaluation of likely social, economic and environmental impacts and suggested significant mitigation measures for the adverse impacts. An environmental reconnaissance survey was carried out based on the guidelines of World Bank and Environmental Protection Law of Yemen. An interaction with the client and officials of Government of Yemen and public consultation with local population were made to record their reactions towards the proposed projects. The general nature and the impacts are briefly discussed in the following paragraph.

The Sana'a basin located in the central part of Yemen highland with absolute elevations varying mainly from 2000-3000 meters above the mean sea level. The climate of the basin is subtropical, mild and moderately continental. Evaporation exceeds precipitation by several folds. The hottest month is July with an average temperature recorded around 22.2^{0}C and the coldest month is December with a mean temperature of 14.3^{0}C. The average monthly relative humidity varies between 35%-55% and the wind velocity between 11 to 15 m/sec. the evaporation from the water surface is about 2500mm/year. Natural vegetation such as Acacia, Ficus, Juniperus, Acanthus, Aloe, and Euphorbia are still common in the mountains and on steep hillsides. In the large plains, the vegetation cover is still relatively dense, with high percentage of bushes and small trees. There are broadly three vegetation types in the plateau with the dominant type is the Acacia mellifera-Euphorbia cactus type. The lower parts of the plains, wadis or terraced parts of the hill sides are used for agricultural production mainly sorghum, maize, qat and grapes.

The potential Positive Impacts are:

- Flood flow storage will benefit the down stream settlements. The natural wadi flow dynamics is now diminished to a great extent. This may have consequences to the down stream aquatic ecosystem.
- The Ministry of Water and Environment in Yemen has indicated that there are no species of plant life or wildlife in the area that have any protected national or international status.
- There are no migratory species or animal movement which would be interrupted.
- An improvement in hygienic conditions and an improvement of water supply will also improve the living conditions of local livestock.
- Improved availability of water for domestic consumption and irrigation purposes.
- Increased agricultural productivity should lead to rising income and improve the living standards for the farming households.
- Continuous domestic water supply to the down stream settlements.
- Employment generation to the local population.
- Potential sites, cemeteries, monuments, forts other features of archeological importance do not exist at the dam sites. No cultural sites will be impacted.

The potential negative impacts include:

- Displacement of population who are living in the reservoir area.
- Pollution from the construction camps.
- Loss of irrigated area.
- Exaction activities during construction have significant impact on the soil.

- Air pollution due to the transport of construction material.
- Pesticides and fertilizers may be washed into the wadis and the proposed reservoirs.

Mitigation Measures Include:

- Introducing anti-pollution clause in the construction contract specification
- Replacement of lost irrigated land.
- No significant impact on the vegetation and wildlife.
- Abatement of air pollution and noise levels.
- Access control for the construction yards.
- Speed regulation and proper traffic signs at the construction sites.
- Remediation of borrow areas.

Impacts during Operation:

- Arid lands transformed into irrigated land.
- Increase in the population at the check dams sites will increase associated problems like sewage disposal and solid waste disposal.
- Greater cropping intensity and greater mechanization in the fields.
- The usage of pesticides will increase from the present usage level.
- Increase in the vector borne diseases like Malaria.

Environmental Management and Training:

- Proper implementation of mitigation measures.
- Training for the officials involved in the implementation of the project.
- Regular monitoring to assess the status of the environment.
- Awareness program to the local population.

The project is expected to result in active participation of the local communities in improved environmental management.

10.3.3 Review of WEC, Sana'a University, Environmental Study

The Water and Environment Center (WEC), Sana'a University, conducted a study in 2001 on the wide spread disposal of wastewater through cesspits. Wastewater has seeped out of the cesspits into underground water sources, and it has substantially deteriorated the quality of ground water. The ground water contamination correlates well with the population density. It was corroborated by different researchers that domestic sewage has been filtered to the ground water via cesspits all over the city. The ground water analysis showed higher values of electrical conductivity, chloride, nitrates, sulphates; bicarbonates and fecal coliforms which are a clear indication of infiltration of domestic sewage.

The wastewater can be treated by land extensive treatment systems like aerated lagoons, waste stabilization ponds, and duckweed-based sewage lagoons. Mechanized treatment systems include activated sludge process, trickling filters or rotating biological contractors. An activated sludge system was considered most appropriate for the city.

Some of the recommendations given by the WEC study are envisaged below:

- The excess sludge should be consolidated and disposed of from the final sedimentation tank.
- The effluents from the wastewater treatment plant should always be monitored.
- Drip irrigation should be used when using effluent for agriculture.
- Sludge should be tested before using for agriculture.
- Continuous soil and water monitoring.
- Specific agricultural crops should be planted based on the water and sludge quality.

10.3.4 Review of the World Bank Regional EIA Study

The World Bank Regional Environmental Assessment Report (2002) and its Executive Summary cover most of the environmental, social, safety issues and management issues pertaining to various project sites.

- The broad objective of the World Bank study is to increase both quantity and the usable life of the ground water resources available in the basin, and increase the efficiency of agriculture water use, so as to allow time for a gradual shift to a less water-based rural economy in the basin. The excessive use of water for agriculture and for municipal water supply has disturbed the balance between the use and recharge.
- The ground water quality for irrigation is quite good in the shallow aquifers of the periphery of the basin and conforms to WHO and Yemeni Standards and guidelines.
- Water quality is suitable for drinking in the deep fossil aquifer and conforms to WHO and Yemeni Standards and guidelines for drinking water.
- There was an increase in the irrigated land of seven folds in the last twenty years.
- One rare species, a succulent plant (Klenia pendula) was located in the vicinity of the proposed project site. This can be easily transplanted and is abundant in other parts of Yemen.
- The new water law has now been ratified which codifies water rights, regulate the use of surface and ground water. A number of shortcoming in the law have been identified,

such as wells less than 60 meters deep do not need to be registered; and these wells are not required to adhere to water extraction requirements.

- Pesticide and fertilizer storage, sale and use are not well controlled, despite the existence of Environmental Protection Law of 1995 which was intended to regulate their use.
- Several of the most common diseases of the Sana'a basin are water related-diarrhea, typhoid and malaria. Schistosomiasis and bilharzias are prevalent in the basin.
- The project activities include demand management and irrigation improvement, supply management and recharge improvement, institutional development and capacity building, information and public awareness campaign, environmental management plan and project management and monitoring.
- Identification of potential environmental and social impacts and their mitigation.
- Environmental monitoring plan: water resources, dam safety, pesticides, public health, wastewater treatment plant.
- Environmental management plan broadly divided into Environmental Mitigation Plan, Environmental Monitoring Plan and Institutional Actions.

10.3.5 Review of EIA Study Prepared for Water Resources Planning Sector

An Environmental Impact Assessment Study was conducted by The Technical Secretariat of High Water Council in the year 1992 for the Water Resource Planning Sector under the UNDP. The objective of National Water Action Plan is to describe strategies and policy reforms that would ensure an optimum allocation of potential available water resources.

The environmental impact is a product of population growth and consumption of resources, particularly land and water. The inadequacy of rain fall and erratic flow of surface waters, led to the over exploitation of ground water in Yemen. The objective and scope of the report is to integrate the environmental concerns with the economic growth at the planning stage. It should adopt a positive approach and should focus on improvements in the health and welfare of the residents of the project area.

The focus for Yemen's water resources sector development should be on environment protection, water conservation and catchment management, and resource sustainability. As water supply sources in Yemen are primarily ground water and used mainly for irrigation detailed planning for the management of water use are essential inputs for environmental assessment of most sector projects. Mitigation measures relating to protection of water quality and improving public health must be primary objectives of EIA investigations for water resources sector projects, or those other projects impacting on Yemen's surface or ground water resources. The following observations made by the team are given below:

- Environmental implications associated with surface waters runoff and storages have not been investigated or documented in any detail for Yemen.
- High nitrate levels are common in many of the surface waters and ground water from the shallow aquifers sampled to date.
- Phosphates are probably the limiting factor with respect to nutrient build up and eutrophication. Storages with potentially high nutrient inflows from seepage of sewerage effluent or agricultural runoff could represent problem situations.
- Small storages are more probable to act as pollutant sinks and should be monitored for both chemical and biological contaminants, particularly if they are used as source for domestic water supply.
- The ground water resources of Yemen are presently of generally good to high quality.
- Some evidence of localized biological contamination of shallow aquifers due to runoff contamination from the urban areas as reflected by higher than background levels of total coliforms and nitrates.
- Slightly high concentrations in some of the quaternary and tertiary volcanic aquifer of nitrates and fluorides. These are likely to be naturally occurring and represent locally minor problems for domestic or community wells.
- Both the deep sandstone and limestone aquifer do not show any signs of progressive deterioration in terms of salinity due to over exploitation from incompatible land use in recharge zones.
- Salinity generally increases from east to west across the alluvial aquifers with some salt water intrusion due to upwelling or penetration due to density differentials occurring in the western sectors and in the phreatic zones along the wadis.
- Ground water monitoring is critical to water resources sector planning and management in Yemen. It is also an integral part of environmental protection, and provides the feedback on the infiltration from waste disposal sites, particularly in those areas where there is a possibility of contamination of shallow aquifers.
- Rapid expansion of groundwater extraction by the private sector for agricultural purposes and lagging development of community water supply and sewerage systems has made the situation worse.
- All of the hazardous waste disposal reports prepared for the EPC comments relating to the risks of increasing groundwater contamination.
- Socio-economic effects would include increased pumping costs for crop production, decreased productivity due to soil salinity, and irrigation water quality problems locally.
- The indirect effects such as increased soil salinity in irrigated areas through water quality deterioration and changes in phreatic vegetation in wadi courses and coastal zones are also potential long term environmental effects of over exploitation of ground water resources.
- The generally poor state of environmental health in Yemen is integrally linked with existing water supply and community, household and personal sanitation practice.

- The extremely high prevalence of gastro-enteric or diarrhea diseases is a major health problem affecting all age groups but most particularly infants and children.
- Parasitic diseases are the third most prevalent group with their occurrences reflecting poor household and personal hygiene with ascariasis being the most common infection.
- The water related diseases of malaria and schistomiasis or bilharzias also have high prevalence rates in certain areas.
- There are number of concerns relating to disease transmission like domestic water supply, sewage disposal, sanitation and waste disposal, disease linkages and control and treatment programs and community health education associated with water resources development in Yemen
- The combined effects of increased irrigated agriculture in place of rain-fed agriculture, expansion of spate-fed terraces through mechanized land development, movement on to marginal lands due to shortages of land, desertification due to regional drought conditions and deforestation associated with land development have resulted in environmental degradation.
- The main land use and conservation issues are:
  - Ground water conservation through improved irrigation efficiency and crop production techniques.
  - Soil erosion prevention and protection through structural, agricultural and ecological stabilization.
  - Re-vegetation and forestation programs to mitigate desertification and provide wood and fodder products.
  - Preparing inventory of flora and fauna and undertaking initial action to protect residual and representative examples of endemic vegetation, habitat and wild life communities.
  - Assistance with land use planning, conservation education, and conservation extension services.
- In the long term, ground water conservation and management plans would need to be included in individual basin management plans.
- Erosion is a major problem throughout Yemen. This applies not only to soil erosion associated with agriculture but also to upper catchments erosion due to topography, hydrology, geology terrace abandonment and tree removal, lowland water course erosion due to peak flows, and erosion by wind. In addition, the problem of erosion is due de vegetation, overgrazing and desertification.

In conclusion it is obvious that groundwater resource planning and management plus supporting legislation and implementation of effective controls on land use, water extraction and waste disposal are essential if Yemen is to overcome its impending water crisis.

These are some of the points discussed in the EIA study conducted for the Water Resource Planning Sector, which was funded by UNDP.

The environmental assessment reports prepared by various agencies throw considerable light on the existing environmental scenario and ground water status and quality of the project area. The reports also extensively speak about the institutional arrangement in implementing the project.

10.4 Legalisation

10.4.1 The Environment Law

The Environmental Protection Law, No. 26 of 1995, is the primary legislation regulating the protection of water, soil and the use of pesticides. It also sets out the control measures for environmentally damaging activities, requiring an EIA process for various kinds of projects, including infrastructure developments of the kind proposed under the present project. Law. No 26 of 1995 also established the Environmental Protection Council (EPC) under the Council of Ministers (Cabinet). The EPC has recently become the Environmental Protection Authority (EPA) and was restructured to fall under the Ministry of Water and Environment.

Part 2, Chapter 2, of the Law deals with water resources and land use planning. in Articles 6 to 10. Part 2, Chapter 2 Article 11 to 15 deals with biodiversity and Part 2, Chapter 2, Articles 15 to 22 refer to the licensing use and storage of pesticides. Law 20 of 1998 concerns seeds and pests and Law 32 Plant Quarantine were enacted in 1999. Following the ratification of any law in Yemen, an Executive Regulation is drafted and issued as a decree by the Cabinet. This sets out the practical arrangements and responsibilities for implementing the law and makes it effective. The Executive Regulations (By Laws) for the Environmental Laws have not been formulated, which leaves the responsibility for enforcement quasi-absent.

10.4.2 Pesticide Law

The Pesticide Law aims to regulate the operations of handling pesticides. It regulates procedures for registration, monitoring, inspection and handling, in order to avoid risks to human and animal health and the environment and to protect the natural enemies of pests and other economically beneficial organisms. The Quarantine Law aims to regulate the introduction of unwanted pests into the country. The laws provisions calls for the establishment of a committee of specialists under the General Administration of the Ministry of Agriculture and Irrigation. This committee will have responsibility for preparing a guide on the registration and handling of pesticides, then establishing a register and registration procedure for those agencies involved in the important distribution and sale of pesticides. The law also makes the provision for the monitoring of pesticides handling and set out penalties for any infringement or misuse.

10.4.2 Yemen's National Environmental Action Plan

The National Environmental Action Plan (NEAP), which was issued in 1996, was based on a national awareness that the well-being of the Yemeni people in present and future generations depends on the nation's natural resources base. The plan promotes the sustainable use of natural resources through a set of policy options in addressing the priority issues. Environmental issues of national concern were identified and environmental analyses were carried out on the major resources assets and economic sectors, particularly on water, land, marine and coastal resources, urban environment, cultural heritage, biodiversity and natural habitats, oil and energy sector, mining sector and the industrial sectors. Consensus on priority issues was reached based on the analysis of the problems according to such criteria as urgency, reversibility, effects on human health and economic productivity. Priority environmental issues and the areas of concern identified in the NEAP are as follows:

- Water depletion, pollution and supply
- Over extraction of ground water
- Lack of water allocation and conservation systems
- Inadequate water supply services
- Land degradation (soil erosion, deforestation)
- Agricultural and rangeland deterioration.
- Loss of farm land due to urban encroachment
- Degradation of natural habitats (forests, wetlands, coastal habitats)
- Loss of biodiversity (extinction of endemic, rare and endangered species)
- Lack of management of ecotourism
- Waste management (solid and hazardous waste)
- Pesticide management

The NAEP promotes sustainable use of natural resources through a set of policy options that deal with legislative, institutional, economic and financial measures, in addition to information and community involvement.

The fundamental strategy used to address priority issues is in the selection and application of appropriate policy option. The following are the outlines of measures selected:

- Legislative measures include development and redrafting of laws, regulations and standards for environmental quality.
- Institutional measures include capacity building of government institutions, universities, NGOs, community and private sector.
- Economic instruments include policies for licensing, incentives, prices, import restrictions, user charges, subsidies, penalties and taxation, which favor sound resource use.

- Financial measures include investments in environmental infrastructure and technology. The private sector and local communities are encouraged to gradually increase their involvement.
- Information instruments involve environmental information management, awareness, research and monitoring. Public institutions, universities, NGO's and public are encouraged to play active roles in collection, analysis and dissemination of data.

The NEAP formed the basis for the environmental chapters in the national population and development plan. It is used as one of the main reference documents by national agencies in planning the environmental work.

10.4.4 Yemen Environmental Legislation Summary

Yemen environmental legislation is relatively recent due to the late awareness of the significance of environmental management issues in sustainable development. Environmental problems started to attract officials and public attention only in the early 1990s. Global conference on environment and requirements from the donors put more emphasis on the linkages between environmental issues and development. The concept of environmental assessments (EA) of projects, participation and sustainable development gradually took their place in the official documents and became a frequent item in the agenda of Government of Yemen. By the end of the century, Yemen had enacted several laws and republican resolutions, bylaws and regulations pertaining directly or indirectly to the conservation of environment and to natural resources. Examples of such legislation include the following:

- Republican resolution (Presidential Resolution) by law number (37) for 1991, territorial sea, the Exclusive Economic Zone (EEZ) and Continental Shelf.
- Law number (43) for 1997 regarding amendments to the Republican Resolution by law (42) for 1992 concerning the regulation of fishing, living marine resources and their conservation.
- Republican Resolution by law (50) for 1991 on Mines and Quarries.
- Republican Resolution by law (11) for 1993 Protection of Marine Environment from Pollution.
- Republican Resolution by law (12) for 1994 on Crimes and Penalties.
- Republican Resolution by law (21) for 1994 on Archeological Heritage.
- Republican Resolution by law (22) on Tourism
- Republican Resolution by law (22) for 1991 on Investment and its amendments by law (14) for 1995 on Investment.
- Republican Resolution by law (20) for 1995 Urban Planning
- Republican Resolution by law (21) 1995 on States lands and property.
- Republican Resolution by law (26) for 1995 on the Protection of the Environment.

In addition, several resolutions issued by the Prime Minister are considered part of the overall legislation. Normally, such resolutions regulate the structure and functions of the government agencies. They are considered legal documents as bylaws and regulations of relevance to the project are the Prime Minister's resolutions:

- Prime Minister's Resolution (94) for 1990 on the Establishment and Formation of the Environment Protection Council and Stipulation of its tasks.
- Prime Minister's Resolution (34) for 1992 on Internal Regulation of the Environment Protection Council (EPC) and its amendment by the Council of Ministers Decree (2) for 2000 on approval of the amendments of the Internal Regulation of the EPC. The EPC is now known as the Environmental Protection Authority.
- Prime Minister's Resolution (148) for 2000 on the Executive Regulation of Law (26) on the Protection of the Environment.

The Environmental Protection Law (26) of 1995 (EPL) embodied the main principles of the Rio Declaration 1992, on Sustainable Development. Among others, the law is based on the principles calling for environment protection, maintenance of balance in the ecosystem and rational utilization of the natural resources for the benefit of the present generation without affecting the ability of the future generation to utilize, these resources. The law gives the responsibility for environmental protection to all parties, emphasizes the incorporation of environmental consideration at all planning levels and the undertaking of environmental impact assessment for developmental projects. The Executing Regulations of the law were issued in 2000.

Conducting EIA studies in Yemen is regulated mainly under the EPL and relevant specific sectoral regulations. The EPL forms the general umbrella law for all environmental policies. It covers the environmental issues and problems facing Yemen. In particular, the EPL defines Yemen's policy concerning EIA in Chapter 3, article 35-47. These articles deal with the environmental assessment (EA) of new and old (i.e. prior to issuance of the law) development and investment projects. The Prime Minister Resolution (148) for 2000 on the Executive Regulations of the EPL covers, interalia, EIA guidelines and projects categories for projects requiring an EIA.

Chapter 3 of the EPL, entitled 'Projects Licensing and EIA' comprises several provisions on the requirements of EIA in projects. The main articles of this chapter and their stipulations are shown briefly in the following table.

Table 10.1 Summary of Chapter 3 of the EPL

Article No.	Subject	EPL Text (unofficial translation)
35	Project Licensing	It is not permissible for any component body to give permission or issue a license to establish or operate or amend projects or establishments that affect and damage the environment or contribute to its deterioration or causing its pollution or participate in occurring such effect or harm human health or other living organisms, only in accordance to the standards or criteria or specifications or conditions that are determined and specified by the council.
36	EIA	It is not permissible to issue licenses for projects and establishments which are by their nature a source of an environmental pollution or that are potentially causing adverse environmental impact assessment statement referred to in this law is undertaken.
37	EIA	1) For the purpose of the environmental impact assessment, the cabinet shall issue a decree for the determination of the standards criteria, specification, conditions and procedures to ascertain and find out whether such proposed project or establishment a) Affects substantially the environment or not b) Some of these standards and criteria are c) Determination of list of projects and their categories which are by their nature liable to create such effects (cement industry- oil refineries-preliminary treatment of mineral facilities-pesticides industry-hazardous waste treatment and storage etc.) d) Determination of lists of special environment sensitivity of areas and locations (the historical and archeological –wet lands- coral islands-natural protected areas-public parks) e) Determination of lists of the resource units (water, equatorial range lands) and environmental problems (increased erosion of the soil and desertification) of importance from an environmental point of view. 2. The decree referred to in paragraph (1) of the article shall determine the elements that shall compose the statement and study of the environment impact assessment, which shall include: a) Description of the proposed activity(map of the location-use of the neighboring lands-the project requirements of water, energy, drainage and roads description of manufacturing operations of the projects-raw materials handling-incidents and risks and safety methods and measures-disposal of waste etc.)

		b) Description of the environment that potentially might be affected. c) Description of alternatives to proposed project (e.g. using materials of least pollution) d) Evaluation and assessment of the probable environment impact and effects of the proposed activity and the alternatives, including those direct and indirect effects, and short and long term accumulations and contains (solid and liquid waste-gas emissions-land uses-noise levels-socio-economic factors) e) The extent to which areas outside the national sovereignty may be affected by the proposed activity.

Articles 38 to 42 discuss the licensing process and responsibilities of the agencies which are mandated to license projects and the necessity to provide the EPA with the EIA of the projects. The articles do not address EIA procedures. In addition; there is no discussion on extensions of existing plants. The Prime Minister's Resolution (PMR) number 148 for 2000 on the Executive Regulations of the EPL comprises seven parts. The first part deals with citation and definitions, while part 2 deals with protection of terrestrial environment. Regulations on protection of air from pollution are under part 3 and protection of the marine environment comes under part 4. Part 5 deals with research on biodiversity resources. Part 6 regulates the establishment of the Environment Fund and part 7 has the transitory and concluding articles.

Part (2) of the Prime Minister's Resolution has five chapters. The first chapter states that relevant agencies are not allowed to issue licenses to project activities which are by nature sources of environmental pollution, or would probably result in environmental damage before an EIA study is submitted. The relevant agency mandated to issue the licenses has to examine the EIA study of the project or the activity on the basis of the elements, designs, standards, rules and conditions issued by the EPA.

- EIA for projects and activities listed in Annex (1) of the PMR are obligatory and must be undertaken by an independent party.
- The agency mandated to give the license must accomplish its work within three months from the date of submitting the application. The licensing agency should inform the applicant of the results of the examination of the EIA. In case of rejection, the letter of rejection should contain the basis of rejection and mention the criteria, standards, elements and required conditions according to the law or the PMR or the resolutions issued on their basis.
- The party whose application was rejected because of non-compliance with the environmental criteria, standards and measures can complain within sixty days of receipt of

the rejection notice. The complaint should be dealt with by the EPA within a maximum period of thirty days of receipt of the compliant.

- The EPA notifies the complaining party and the agency mandated to issue the license on its resolution regarding the complaint.
- The EPA upon receipt of the complaint may approve the project or activity on the conditions that monitoring equipment for waste disposal and pollution are installed. Permanent or temporary records for this purpose must be kept. The licensed project or activity owner must keep the records and submit reports on them to the EPA every six months.
- Resolutions of the EPA on the complaints are obligatory to the licensing agency.

Article (4) of this Chapter deals with the requirement that the list of projects and activities in Annex (1) and their extensions renovations, must have an EIA. Article (5) deals with the application and the forms issued by the EPA to be completed, and other relevant procedures.

The second chapter of Part (2) of the PMR deals with Hazardous Materials and Hazardous Wastes. This Chapter has three sections (branches) dealing with General Provisions, Hazardous Materials and Hazardous Wastes respectively.

Chapter (3) of Part (2) of the PMR deals with water and wastewater. Chapter (4) regulates the natural protected areas and the final Chapter (5) deals with facing natural catastrophes.

Part (3) of the PMR deals with protection against air (atmospheric) pollution. This part made up of (17) Articles inclusive of Articles (40) to (56). Articles number (40) stipulates that without violation of the provisions in an EIA, it is obligatory in any fixed site which emits air pollutants. The following:

- The site should be suitable to the activity (of the project) taking into consideration its distance from residential areas, direction of prevailing winds according to the decisions of the Public Works and Urban Planning.
- The total quantity of all pollutants resulting from all the fixed sites in a single area must be within the allowable limits detailed in Annex (5) of the PMR

Article (41) stipulates that each project or activity is not allowed to emit or leak quantities exceeding the maximum limits detailed in Annex (6) of the PMR. It is not allowed (for a project or activity) to cause any change in the characteristics and specifications of the natural air which results in danger to human health or to the environment.

Article (42) regulates emissions from vehicles, mobile machinery and equipment and specifies the quantities of emissions of carbon monoxide and hydrocarbons at specified speeds and rotations per minutes.

Article (43) gives Ministry of Agriculture the mandate to regulate the conditions for spraying and use of agrichemicals and pesticides in coordination with EPA.

Article (44) mandates the Ministry Public Works and Urban Planning to issue the conditions for collecting and transporting garbage, solid waste, construction waste and dust from drilling, construction and demolition.

Article (45) stipulates that medical wastes must be burnt in incinerators approved by the Ministry of Public Works and Urban Planning and the EPA provided that no gases are emitted by these incinerators exceeding the limits detailed in Annex (6).

Article (45) stipulates that all projects which, during its activities, burnt any fuel or other materials for any purpose must consider that:

- Smoke, vapors and gases emitted must be within the allowed limits.
- All possible measures are undertaken to minimize pollutants resulting from burning.

Article (47) establishes the following:

- Forbids any project with a chimney to be established unless the height of the chimney is approved by the EPA.
- The EPA must make sure that the height of the chimney under the best practical conditions will be adequate to prevent smoke and emitted gases from causing damage to health or the environment.
- The EPA may give its approval with certain conditions.

Article (48) makes it obligatory for any agency, project or activity which emits harmful materials or unpleasant odors mentioned in the second section of Annex (6) to provide the best practical means to prevent these emissions, the harm and damage resulting from them.

Article (49) mandates the EPA to ask the agencies, owners of projects, and other activities which emit material classified by the EPA as harmful or unpleasant and not mentioned in Annex (6) to use the best practical means to limit the emission and prevent it from causing harm or damage.

Article (50) stipulates that all bodies (agencies) working in searching, exploration and production of crude oil, refining oil, storing and transporting it must comply with the controls and sound measures which fit with the principles, standards and basis of the international oil industry and controls put by the Ministry of Oil and Mineral Resources and its specialized agencies.

Article (51) stipulates that control of noise in the general environment is subject to the rules mentioned Annex (7) of the PMR.

Article (52) regulates noise production inside places or in closed areas, while Article (53) vests the authority of putting in coordination with EPA the limits of emitting air pollutants inside offices and the maximum and minimum limits of temperatures and humidity in offices.

In Article (54), each person directing an agency or a plant is obliged to take measures to prevent smoking in closed public places except in areas specified for smoking.

Article (55) mandates EPA to establish stations in definite areas to monitor air quality and identify such areas while Article (56) obliges the EPA, in coordination with the other agencies, to scrutinize, follow up and make regular monitoring of air quality.

Article (55) also obliges the competent authority to study and evaluate the general status of general cleanliness and the extent of danger from the types of garbage components, sewage disposal, solid, and liquid wastes. In particular, it determines:

- The landfill sites in coordination with the EPA
- The methods and conditions of disposal of solid, liquid wastes, or their burial or transporting the wastes or ridding of them in any manner in the territorial waters.
- Other measures to be undertaken which the EPA deems necessary to prevent the dangers from such disposal and the competent authority has to notify the EPA of the results of the study and evaluation.

Part (5) deals with environmental conservation and economic development. It discusses in Articles (56-57) the considerations of environmental protection, combating pollution, and rational utilization of natural resources.

Part (4) of the PMR deals with the protection of the marine environment from pollution. This part has three Articles numbered (57), (58) and (59). In articles (57) the Public Corporation for Maritime Affairs (PCMA) has to coordinate its efforts with EPA in its application of the Law of Protecting the Marine Environment from Pollution (PMEP) Article (58) stipulates that:

> *It is not permissible to issue a license for constructing any installation or place (plant/shop) on the coastline or near it which releases polluting materials in violation of the PMEP and the EPL Articles and the decisions (resolutions) issued on their basis.*

All installation and places mentioned in paragraphs I of this Article must provide adequate and suitable units for waste treatment and start operating them when the installation or places start operations. These units must be ready and operational at all times.

Article (59) stipulates that it is not permissible to install (establish) any plant on the shores of the Republic of Yemen especially on sites of important marine biodiversity and environmental sensitivity. The EPA must specify these sites and they must be issued by a cabinet decree.

Part (5) of the PMR deals with four Articles (60-63) with research on living resources (biodiversity) while Part (6) has one Article on the establishment of the Environment Fund including its revenues and expenditures.

10.4.5 Solid Waste Management

The EPL obliged the competent authorities in Articles (55) discussed above to study the extent of the dangers of the components of garbage, sewage and liquid wastes. The specific law (40) for 1999 on general cleansing deals in more details on the solid waste and public health. It vests the authority of supervising and following its implementation in the Ministry of Public Works and Urban Planning (PWUP). The law has six Chapters in 44 Articles. Chapter (1) has the name of law, definition and objectives while the last Chapter has general concluding provisions. Chapter (2) addresses the collection and transportation and disposal wastes. Article (5) obliges each natural or legal person not to throw, place or leave waste in the squares, plazas, gardens, streets, pavements, passages and alleys whether public or private or putting wastes on the roofs, balconies of buildings, beaches, agriculture areas, flood paths, wadis, and open land. It forbids burial, burning or placing waste in places other than those specified by the PWUP. Article (6) obliges everyone to put waste in covered containers and Article (7) obliges the PWUP to place well covered boxes, barrels or containers in specified areas. Article (8) regulates transportation of wastes and Article (9) regulates wastes from workshops, industries and other institutions. Chapter (3) deals with transportation of liquid wastes and their disposal. In Article (11) the PWUP is to coordinate with the offices of National Water and Sewage Agency (NWASA) concerning the suitable places for treatment and disposal of solid waste and wastewater, lubricants wastes, industrial waste and other urban wastes and the conditions for disposal Articles (12-16) deals with specific requirements for disposal of the various types of wastes. Chapter (4) deals in Articles (17-22) with land fills. Chapter (5) regulates contracting the works of collection and disposal of wastes to private contractors. Chapters (6) in Articles (30-37) specify penalties for various violations of the provisions of the law.

10.4.6 Administrative Framework for Environment Assessment / Management

According to Decree No 89 for 1993 of the Cabinet and section three of EPL, the EPA administers the EIA process and other requirements and procedures included in the EIA legislation. This not only involves the responsibility for drafting regulations, guidelines and standards but also involves a central position in preparation of terms of reference (TORs), review of EIA reports, and the monitoring process. Within the EPA, the responsibility for EIA rests with the General Directorate for Monitoring and Environmental Assessment (GDMEA), which liaises with and provides advice to the competent authorities. The GDMEA can use any technical staff within EPA or any specialized person from universities or line ministries or outside of these institutions, if needed.

The existing regulations do not specify EIA procedures to be followed by the investors or the beneficiary institutions. However, certain procedures have gradually developed since the issuance of the EPL in 1995. A number of elements were considered including the type of project, the financing agency, requirements or conditions of the donors, the client ministries or institutions, and their comprehension of environmental regulations. The following steps relate to the role of the EPA in the EIA procedures required:

- The Ministry of Water and Environment (MWE) and the EPA, as lead agencies, decide whether a project needs an EIA or not. This decision is arrived at in collaboration with the line ministry, or developer or donor or investor. Project proposals by relevant collaborating body have to be submitted to the MWE and EPA for such decision.
- Scoping and preparation of Terms of References is an important role of the MWE and the EPA. Jointly with the benefiting body mentioned above the TOR s for the EIA study are prepared/ revised and approved by MWE/EPA.
- Conducting the EIA is normally carried out by an independent private consultant or consultancy firm. Participation of the EPA and the concerned bodies is required in ascertaining that the EIA follows the guidelines and scope of the study prepared by the EPA. The objective of the participation is to train the staff from the EPA and line ministries on the various aspects of EIA preparations. The costs are borne by the investor.
- General consultation is undertaken by the consultancy firm, in coordination with the EPA, through organizing a meeting or workshop that includes the EPA, through organizing a meeting or workshop that includes the EPA, other relevant government agencies, the donors and representatives of local communities affected by the project.
- Reviewing the EIA report is carried out by the MWE/EPA. No fees are required for the review except when the EPA hires other professionals to review the EIA report. In this case the fees for them have to be paid by the investor/relevant ministry.

- Final consultation is carried out by the EPA to check if the comments during the review were incorporated in the final EIA report.
- Evaluation of EIA is carried out by the EPA. The evaluation would result in acceptance or rejection of the EIA study.
- Final decision and environmental clearance is to be made by the MWE through the issuance of a clearance letter. The letter would be based on the decision of the EPA on whether the proposed project is environmentally acceptable or under what conditions it would be. The letter would include conditions, mitigation measures needed, monitoring requirements or requirements for operation and maintenance.

10.4.7 The Water Law

Recently, a Water Law was approved by Parliament in July 2002. The long awaited Water Law fills a large legislative gap in the Yemeni Law. The Water Law sets out the responsibilities for managing and planning water resources, their protection and conservation, and sets out procedures for licensing water use and penalties for contravention of the law. The law specifically deals with the roles and responsibilities of central and local governments, traditional water rights, and priorities for use, spate irrigation and ground water abstraction. However, the law as it stands has a number of flaws, mainly, it does not provide for measuring water abstraction, it does not provide for the levying of water use charges for agriculture, the law allows for the wells to be constructed up to 60 meters deep without a license and all past water rights are grand-fathered. As traditional water rights already exceed recharge by more than 100% the effectiveness of the law in water conservation is limited at best. Article 49 of the Law provides for areas to be zoned as "Water Conservation and Protected from Pollution". It would seem appropriate to zone the Sana'a Basin as protected and draft specific guidelines for water conservation and use in the area.

Following the ratification of any law in Yemen, an Executive Regulation (by Laws) must be drafted and issued as a decree by Cabinet. These set out the practical arrangements and responsibilities for implementing the law and make it effective. Unusually, Article 126 of Water Law states that the Executive Regulation must be passed within six months of the ratification of Law. An expert committee chaired by NWRA is presently drafting the Executive Regulations. Guidelines and Standards for wastewater reuse based on FAO and WHO standards were issued earlier in 1993. Similarly standards for drinking water based on WHO standards were issued in 1999.

10.4.8 Land Acquisition

Article 8 of the Yemeni Constitution, vests ownership of all underground natural resources (including water) in the State to be held for the benefit of the people. In addition Yemeni Law (Law No.1 of 1995, Appropriation of Property in the Public Interest) makes provision for the acquisition of land and sets out three methods of determining compensation by mutual agreement by court order or by providing an equal alternative site. However there are number of cases were the heirs of individuals or tribes have contested land transfers by oral mutual agreements, which have no legal validity.

10.4.9 World Bank Policies

The Consultant responsible for the preparation of the Detailed EIA should follow a number of existing World Bank policies and guidelines.

In addition to the Yemeni Laws, the Detailed EIA will be prepared based on the World Bank guidelines viz. Operative Procedures (O.P) 4.01. A number of safeguard policies shall be adopted while preparing the report. The major policies which include the Environmental Assessment (O.P 4.01, Bank Procedures (BP) 4.01, GP 4.01), Pest Management (OP 4.09), Involuntary Resettlement (O.P/BP 4.12), Safety of Dams (O.P 4.37, BP 4.37), Cultural Property (OPN 11.03), Indigenous People (OD 4.20). The policies on Natural Habitats and Cultural Property are not considered triggered by the proposed project, as identified potential impacts are rather insignificant. Field surveys encountered only one rare species of plant, which would be transplanted if encountered during the construction. There are no known archeological sites near the proposed work sites.

10.5 Background Environmental Information

10.5.1 Location

Wadi Bahman is located in the Beni Hushaish District. It can be reached via the Sana'a to Ma'reb highway. There are about five settlements along the wadi. Agriculture is the major activity of the population living in the project area. The catchment area is around 10.16 square kilometers. Check dams are proposed on wadi Bahman. Wadi Bahman joins Wadi Al-Sirr.

10.5.2 Topography

In general the catchment area is hilly and mountainous with steep slopes and barren rock. The elevation of the uppermost point of the catchment is about 2740 m while the lowest point is at about 2200 m above mean sea level. The dominant type of bedrock in the Bahman valley is fine-grained sandstone with calcareous cement.

The country is dominated by the mountain ranges running parallel to the Red Sea coast through Sana'a towards Aden, with three ridges interspersed by an upland plain. These mountains merge with ranges rise from sea level to over 3700m within 100 km from the red sea coast, running to the coast of Gulf of Aden, which reach altitude of 2000 meters mean sea level. Yemen can be grouped into five main geographical regions viz. the coastal plains, Yemen Mountain Massif, Eastern Plateau Region, Desert, and the Islands.

10.5.3 Land Use Pattern at the Site:

Cultivation is observed on either side of the wadi. The main crops are qat, grapes, fruits and vegetables cultivated in irrigated lands. Food crops, such as grains, maize and other cereal crops are produced from rain fed lands. Residents of the village are living on either side of the wadi.

10.5.4 General Land Use Pattern:

The land use in upland areas of Yemen, particularly in the north, is based on the unique practice of bunding and terracing which permits reliance on rain-fed agriculture. This is impeding the immediate runoff and erosion which the topography would otherwise allow, and ensuring the recharge of soil moisture and local ground water. This terracing is ancient and highly labor intensive, with entire hill side covered with stone bunds and earth banks interspersed with terrace areas, which may be as narrow as one meter in steep catchments. It is noteworthy that runoff is delayed during storms, with the terraces flooded as though with surface irrigation, and this allows the cultivation of cereals and vegetables in areas of steep slopes and sporadic storms.

10.5.5 Agriculture & Livestock

Wadi Bahman is located near Bahman village, which comprises Al-Jab Baila and Baith Joban. Combined, these areas have a population of 4,500 which is made up of over 200 households. The main livelihood of this area is cattle rearing and cultivation. The total cultivated land in the village is about 548,108 square meters. Of this area, qat is cultivated in 22,220 square meters and grape is cultivated in 444,400 square meters and fruits and vegetables are grown in 81,488 square meters. The Bahman catchment is unusual in the fact that qat comprises a relatively small amount of the total cultivation. Water for various activities is obtained from the existing open wells and tubewells. There are about 50 open wells and 3 tube wells. There are about 200 cows, 1500 sheep and 300 donkeys within the project area.

10.5.6 Traditional Terrace Farming

The use of slope runoff on terraces represents a resourceful ecological response to fluctuations in rainfall and the relative lack of suitable soil in much of the mountainous area.

The ingenuity of terrace construction is still quite visible in the Yemen highlands. Farmers considered a variety of factors in the local terrain in order to maximize water collection but not to the point of erosion stress. A slope is rarely continuous, so existing rocks and boulders are often incorporated into terrace walls. The rock for terrace walls is generally available locally, but soil usually has to be brought from other areas. In the past, conveyance of soil was accomplished by donkey load from alluvial fans far downstream of the terraces.

Most terraces are constructed to take advantage of the local water regime. Where there is a spring or spring line, terraces will be located in clusters below so that gravity flow sequence can irrigate the systems as a whole through a common channel network. In these spring fed irrigation systems the water may descend through channels over one kilometer to the farthest plots. In higher mountain slopes, where runoff harvesting is practiced, a group of terraces will be arranged so that excess flow will be carried off through the channels.

The basic subsistence crop was sorghum, which provided grain for bread and porridge and leaves and stalks for much needed fodder. While most of the sorghum produced by a household was consumed at home, the fodder value of the plant represented a potential source of income in the market. On irrigated land, where sorghum plants may reach up to three meters, the market value of the leaves and stalk is quite high. Legumes such as cowpeas were often intermixed with sorghum; a practice which in fact enriched the nutrient level of the soil. The two major cash crops in Yemen's recent past have been coffee and qat, which can be grown on rain fed or irrigated land.

The highland terrace systems require proper maintenance not only to preserve the agricultural land of the terraces, but also to limit erosion of prime irrigated land. This is because the water regime in a given water shed results in a balance between the control of land and water in the upper catchment area and the resulting flow of water in the major wadi systems descending to the productive coastal plains. It is now possible to measure the pace of destruction from the abandonment of highland terraces in the form of a dominant effect of erosion down the wadi. The stripping of plantation in the upper catchment results in barren, soil-less escarpment with major sheet and wadi erosion down the length of the system. To make matters worse, gravel and silt carried by the wadi waters accumulates large amounts of silt at major dams.

10.5.7 Climate

The predominant climate is arid and semi-arid. The country can be broadly divided into three climatic zones.

- Arid tropical climate, which covers the coastal plains region and lower mountain slopes in the west and south and is characterized by high temperatures and low precipitation ranging from 0-400mm.
- Arid sub tropical climate, which is a transitional climate between the tropical climate of coastal plains region and the temperate climate of the highland region. Mean monthly temperature varies from 16^0 C to 28^0 C. precipitation ranges from less than 100 mm to 600 mm. It covers the lower and upper mountain slopes and the eastern plateau region.
- Temperate climate, which covers the mountains ranging in altitude from 1800 to 3700 m above sea level. Mean monthly temperature in this climate ranges from 10^0 C to 18^0 C. Precipitation varies from 200 mm to more than 1200 mm.

Although the south western parts of Yemen receive significant rainfall in spring and summer, precipitation is reduced as the wind pass over the high peaks of the western slopes and plateau areas. By time the winds reach the interior zone, they are too dry for any major rainfall event.

10.5.8 Rainfall

Rainy seasons occur during the spring and summer. The climate is strongly influenced by the mountainous nature of the country. Two main mechanisms guide the rainfall in Yemen, the Red Sea convergence and the monsoonal inter tropical convergence zone. The former influence is most noticeable in the west of the country; this is active from March to May and to some extent in autumn, while the later reaches the country in July–September, moving north and then south again so that its influence lasts longer in the south. Seaward exposed escapements such as the western and southern slopes receive more rainfall than the zones facing the interior. The average temperature decreases more or less linearly with the latitude.

10.5.9 Temperature

Average temperatures are dominantly controlled by elevation. There is an approximately linear relation distributed by the proximity of sea in the coastal areas. The annual temperatures range from less than 12.5^0 C in the central highlands to $30^{\ 0}$ C in the coastal plains. However, winter temperatures may decrease to freezing temperatures in the highlands.

10.5.10 Soils

The soils are generally sandy to silty and loamy in the coastal plains, silty to loamy and clay loamy in the mountain areas, with low nitrogen, phosphorus and organic matter. In many areas, shallow soils limit the amount of water available for rain fed crops. Soil erosions caused by runoff and or winds are often serious. Sand and dust storms, which generally blast across the lowlands and highlands, promote erosion.

10.5.11 Geology

The northern part of Yemen belongs to the southern portion of the Arabian plate. Since the upper Cretaceous, it has been separated from the African plate. During this period, the Red Sea Graben was formed. The general geology of the Sana'a Basin is like a Precambrian basement and it consist of metamorphic and intrusive rocks, which outcrops mainly in the northern and southern part of the area. These formations are mainly composed of meta-sediments and meta-volcanic intruded by granites lavas. Intense folding in a general north – south direction occurred at the same time as the formation of these rocks. After a period of uplift, denudation and the formation of a pen plain, sedimentation took place during the Ordovician, resulting in the formation of a series of fluviatile sandstone and conglomerates. Mountain glaciers covered the southern high lands during the Permian age. Their moraine deposits were reworked transported and re deposited in a sequence of claystones and siltstones with glacier transported boulders. In the central part of northern Yemen, the Tawilah deltaic cross bedded sandstones and the conglomerates are covered by a Paleocene marine series of sandstones and claystones deposited.

10.5.12 Site Geology

The geology of the proposed site at Bahman consists of Tertiary rhyolite and dacite in the wadi Bahman area, at the level of the wadi and up the valley wall for a fair elevation, the Tawilah sandstone only was observed. The Tertiary igneous does seem to cap this sandstone, but has no influence on the project site. It is considered certain that the porous and permeable Tawilah sandstone underlies the wadi's alluvial deposits in the same way as it outcrops along the banks.

10.5.13 Water Resources

Surface Water

There are four major drainage basins in the country with numerous smaller wadis. The drainage basins are the Red Sea basin, the Gulf of Aden basin, the Arabian Sea basin and the Rub al Khali interior basin. The smaller wadis in the country are generally characterized by abrupt flooding and they rapidly recede. Mostly flooding occurs during the monsoon season leading to the loss of productive agricultural soils along with the wadi water and increasing sedimentation and significant widening of downstream wadi bed.

Surface Water Contamination

In regard to runoff; water quality varied from site to site. During the significant rainfall events, floods produce surface flow in the wadis. This originates exclusively from the surrounding mountains. The proposed dam site receives runoff from the mountainous upstream, which forms part of catchments. The runoff contains large amounts of suspended solids and debris. In addition the flood waters commonly contain dissolved solids, domestic wastes, gasoline, oil, and rubbish. Evaporation can be expected to concentrate pollutants in the water bodies. High nitrate and phosphate levels are common in many of the surface waters and ground water from the shallow aquifer.

Water Quality at the Site

Testing of the water samples showed TDS 767 mg/l, chloride 137 mg/l, nitrate 22 mg/l and iron of less 0.8 mg/l concentrations in the samples collected.

Ground Water

Ground water is the principal source of water in the region and the main source is from three aquifer layers, namely alluvial deposits, volcanic units and the Tawilah sand stone. Tawilah is considered to be most productive and yields the best water quality. The excessive extraction of ground water has resulted in a substantial drop in the ground water. If the present pattern continues in the basin than it would lead to a permanent scarcity of the natural resource. The water consumption for the domestic and industrial use is small when compared to agriculture. Agriculture consumes 80% of water in the basin area. Out of the 80% the cash crops qat and grape consume 40% and 25% of the water used for irrigation purpose.

Groundwater Contamination:

Ground water pollution sources can be conveniently placed into six major categories, these include municipal, agricultural, industrial, oilfield wastes, mining wastes, and miscellaneous sources. But in the present dam project the major ground water contamination occurs mainly from agricultural runoff, sanitation, domestic waste water and oil from the pumps used for irrigating the fields.

Agricultural Sources

Agricultural activities are the most important potential source of ground water pollution. In the arid regions especially, evapotranspiration and leaching is likely to be a major process leading to deterioration of ground water quality. Return flows, some 30-40% of the total irrigation water delivered to farm fields, percolates through the soil to the ground water. Because of evapotranspiration, its mineral contents sizably increase in many situations.

Fertilizers are being used in modern agriculture, and are applied to almost all crops. Their application rate usually varies with crop types, soil conditions and irrigation practices. Relatively high cost has limited the use of fertilizers, pesticides and herbicides in Yemen. Although return flow may include agricultural chemical residuals, including toxic biocides, many pesticides are retained in the soil or degraded, while some have been found to be readily leached into the ground water.

Other Sources of Pollution:

The second important potential sources for ground water pollution in the rural areas are cesspits (on site sanitation). These facilities provide a substantial pollution load on ground water. In some cases, wastewater is used to irrigate fields contaminates shallow aquifers. Elevated nitrate levels are very common in the surface water and ground waters. Another potential pollution source is the dumping of rubbish in wadi channels by the rural population. Waste oil from cars, leakage from petrol storage areas and irrigation machines also contaminate the ground water to a great extent.

10.5.14 Biological Environment

Yemen is very rich in flora and has a wide range of natural vegetation types, a mixture of species from East Africa, the Sahara-Arabia, and the Mediterranean. The vegetation coverage ranges from 9% to 43% and is dominated by grasses and dwarf shrubs. A list of endangered plant species in Yemen is not available, but some 27 additional species are considered endangered at the national level. Medicinal flora is not well documented in Yemen. However, along the Bahman wadi where check dams are likely to be constructed, no endangered plant species were observed.

The fauna comprises 71 species of mammals. Five species of gazelle have been recorded, four of which are believed to be almost extinct in the country. Other species are ibex, Oryx, baboon, red fox, wolf, hyena, jackal and bats. Among the most notable is the Arabian Leopard, which is considered endangered or already extinct and the cheetah, which was not been seen in the wild for a long time. Yemen is very rich in bird life and more than 350 species have been recorded.

Major threats to flora in Yemen are cultivation and poor agricultural practices, wood cutting for timber fire wood and charcoal, over grazing, soil salination, wind erosion and expansion of villages and cities. The major threats to fauna are over-hunting, killing of animals perceived as dangerous such as snakes, and destruction of habitats through deforestation and urbanization.

10.5.15 Health Status

Dams and related water infrastructure projects continue to be planned, constructed and operated to meet the human needs through agriculture production and supply of drinking water. The aim is to achieve important socio-economic development of the rural areas. The main water borne diseases of concern is cholera. Out breaks of cholera have occurred in the recent years in several locations. Specific data on incidents of cholera are limited as they are most frequently recorded only as out breaks. The extremely high prevalence of gastro-enteric or diarrhea diseases is a major health problem affecting all age groups but most particularly infants and children. Diarrhea is the second most prevalent disease after acute respiratory tract infections in Yemen. It is estimated that about 30% of infant and children deaths in Yemen are caused by diarrhea and associated dehydration. Parasitic diseases are the third most prevalent group with their occurrence reflecting poor household and personal hygiene with ascariasis being the most common infection. The waterborne diseases of malaria and schitosomiasis also have prevalence rates in certain areas. Indicated rates for infected carriers in Sana'a region are 10% and 3% for malaria and schistomiasis respectively.

The availability of a disease free and secure water supply is fundamental to reducing and maintaining acceptable levels of gastro-enteritis diseases in urban and rural communities. The other conditions are unhygienic and poor disposal of wastes which contaminate water courses and shallow aquifers.

Historically malaria had a low prevalence rate in Yemen, but with increasing urbanization, irrigation development and mobility of residents; the disease is now endemic except at higher elevations. Both types of schistosomiasis or bilharzias occur in Yemen. They occur in perennial water bodies like springs and seepage flows. There is an indicated schistomiasis infection rate of 3% in the Sana'a area based on medical reports.

A proper safe water supply and proper disposal of solid waste would control a number of diseases occurring in the region.

10.5.16 Places of Archeological Importance

Sana'a is administratively divided into the capital secretariat of the county and Sana'a surroundings; together they form the Sana'a Governorate.

Sana'a Capital City

The historical capital of the Yemen Republic is situated at the center of plateau between two mountains of the Sana'a Basin. These are the Nuqum and Ayban mountains. In the capital, the old Ghamdan Palace is situated at the foothills of the Nuqum Mountain. One of the ancient land marks of the city was its ancient wall with seven gates. Today only one of them, locally known as Bab-al-Yemen, remains. It is located on the southern direction of the city. Among the main land marks of the city are the "Big Mosque" considered the eldest in Yemen; others are the "Copper Samsara" where the largest old market is located; "Manuscript Dar;" The National Museum; Military Museum; Museum of Archeology; and the Museum of Popular Heritage. The city is also surrounded by some naturally magnificent parks.

Other important places near the Capital City are Al-Rouda village with its old mosque, which dates back to the seventeenth century. Wadi Dhahar is located 14 km north-west of Sana'a. It contains "Dar-al-Hajar" an old palace built during the rule of Imam Al- Mansoor. Haddah, about 8 km from the city center, has some old mills which were built during the Ottoman rule in Yemen, and were formerly driven by the force of water currents.

Sana'a Province

There are some historical and archeological sites in Sana'a Province. The archeologically important places are listed below:

Ghaiman

An old archeological village located 20km east of the capital. Its ruins bear witness to the level of civilization achieved in the village before Islam. There are some ancient tombs of Yemeni kings, along with large water reservoirs.

Di-Murmer Castle

Situated 18 Km east of Sana'a, the castle is located in an area known as Shibam-al-Farass. Shibam Castle was among the important commercial centers for traffic of commercial caravans. Ancient mummies have been found inside rocky-built burial chambers. Ancient people of Yemen practiced the art of mummification using a different procedures than the one practiced by the ancient pharaohs of Egypt.

Bilad-al-Rous Turkish Bath Centers

A naturally splendid resort located in Al-Hazz Wadi, south of the capital.

10.5.17 Socio-Economic Aspects - Bahman

Bahman village is located in between two sides of a wadi where some water check points are locally made. The sheikh of the village, Abdul Hamid Al-Moafa, and the local population participated in group discussions and the individual interviews.

People indicated that agriculture is the main source of income, as various crops are grown in the area such as grapes, qat, vegetables, and some fruit trees. Vegetables are mostly grown for local consumption. About six bore wells were found in the village with depths varying between 300-400 m. Surface water flows are found in the wadi branches, but surface wells were dried as indicated by people.

There is one school and one health center at Bahman. These facilities were built through local people's initiatives and cooperation. One person donated a house to be used as a small health center. Additionally, electricity and telecommunication services are found in the area.

There are some efforts by the sheikh to establish a water users association, in order to improve water conservation in the area. It was indicated that drip irrigation would be a good solution, but this is not expected to become viable until after people are convinced about its economic use and suitability for their crops and conditions. It was noticed that there is soil erosion problem in the wadi banks. People indicated that there is a need for soil protection measures.

People in Bahman believe that building check dams would benefit the area as agricultural and livestock production will increase, and recharge of surface water will take place.

10.6 Environmental Impacts

10.6.1 Introduction

The construction of the check dams would lead to both positive and negative impacts on the environment. The check dams proposed would considerably improve socio-economic status of the rural population. The projects would help in alleviate the poverty, provide food security and improving the quality of life for rural population. Check dams would take less time to construct and not labor intensive. The expenditure for the construction of a check dam is much less when compared to the bigger dams. Check Dams are good for the ground water recharge.

The present section identifies environmental impacts that must be considered during the design, construction, and operation stage of the proposed check dams. Suggestion for reducing, mitigating and eliminating these potential impacts follow each section.

10.6.2 Impacts during Construction

The rehabilitation works will affect the environment to a negligible extent. The likely impacts are site specific and limited to the areas where work will be completed within the wadi. The nature of construction is temporary, and potentially negative environmental impacts can be mitigated using suitable measures.

10.6.2.1 Air Quality

- Civil works at the site would generate air borne dust.
- Emission from the construction machinery would generate emissions that would negatively impact the local air quality.

Mitigation Measures
There are common mitigation measures which are effective in controlling the emission from the construction activities. These will be used at the construction site to curtail the emission. The construction machinery should be well maintained, properly greased and should be switched off once there is no work.

10.6.2.2 Noise level

Temporary impacts in the immediate vicinity due to noise generated from construction activities.

Mitigation Measures
The mitigation of noise levels will be done by implementing the following suitable mitigation measures.

- Construction equipment should be built with silencers or mufflers should be installed and properly maintained.
- Construction workers, who are exposed to high noise levels, should be provided with earplugs. In addition the construction labor would be provided with protective helmets, foot wear, and hand gloves.
- Construction activities involving operation of high noise generating machinery should be avoided between 10 p.m. and 6 a.m. in areas near villages.

10.6.2.3 Construction Yards

Storage of construction material, chemicals, oils and lubricants must be carefully controlled.

Mitigation Measures

The mitigation measures can be easily implemented for the adverse impacts caused at the construction yards. The mitigation measures suggested are as follows:

- Construction yards should be placed away from the human settlements.
- The Environmental Management Plan shall be followed by the Contractor, and enforced by the Engineer.

10.6.2.4 Construction Camps

A Construction camp is proposed to be located at one the side of Wadi Bahman. The impacts caused by the construction labor camp are envisaged in the following points:

- Wastewater generation from the construction labor camp.
- Domestic solid waste generation.
- Migration of labor from neighboring settlements for employment.
- Incidence of diseases due to unhygienic way of living by the migrant labor.
- Liquid waste particularly oil and lubricants from machinery and trucks used during construction.
- Medical waste and hazardous x-ray films and chemicals from the health care unit at the camp.

Mitigation Measures

The impacts can be easily mitigated by implementing the mitigation measures, but certain provisions to be given to the work force.

- Proper wastewater treatment for the domestic wastes; at least provision of soak pits.
- Provision of toilets and septic tanks.
- Provision of a proper drainage system at the labor camps.
- Provision of cooking fuel, so as to reduce any cutting the trees for fire wood.
- Provision of electrical lighting provision.
- Water and drinking water facilities provision for the worker camps.
- Used oil and lubricants must be collected and disposed off away from the site.
- Developing vegetative cover around the construction camp.
- Health facilities will be provided either at the construction labor camp or near by place.
- Health awareness campaign among the labor camps and create awareness among the worker about the health.
- Construction phase would generate employment to the local population.

10.6.2.5 Impact on Flora

There will be no significant negative impact of project on vegetation due to air and noise pollution during construction phase of the project. No significant impact is envisaged on the plantation surrounding the project site. There are no biodiversity sites as such near the area. Qat farms will be inundated.

10.6.2.6 Impact on Fauna

There will be not be any significant negative impact of project on the local fauna due to air and noise pollution during the construction phase of the project. There are no forest areas or biodiversity areas near the sites.

10.6.2.7 Impacts of Archeological/ Historical Monuments

There are no archeologically or historically important places near the reservoir areas. No burial grounds were located near the proposed site.

10.6.2.8 Impact on the Geology and Topography

There are no anticipated impacts due to the construction and operation of the proposed check dam structures. The preliminary geological investigation showed that the area is suitable for construction of the check dam. There will not be any major impact on the geology and topography of the area.

10.6.3 Impacts during Operation

10.6.3.1 Check Dam

- Benefits of check dams increases agricultural productivity and control the flood water, and improve the ground water recharge.
- The project implementation would increase the agricultural production and bring in the social well being of the rural population.
- The incidence of the diseases will less when compared larger dams
- Smaller dams have advantage of shorter construction of time, smaller capital costs, shorter gestation period with early benefits and the will lead to better development of the rural areas.

Mitigation Measures

- No anthropogenic activity to be entertained near the proposed check dams.
- Provision of proper health facilities to the local population.

10.6.3.2 Water Quality

The impacts water qualities in the reservoir are as follows:

- Agricultural runoff from terrace cultivations
- Increased amounts of domestic wastewater.

Mitigation Measures

The adverse impacts can be curtailed by adopting proper mitigation measures.

- Adequate planning for design of the community water supply and sanitation including careful management of sewage and domestic waste. Prevention of Wastewaters joining the water at check dams.
- Supportive infrastructure such as safe domestic water supply.
- The sanitation facilities should be away from the rural water supply schemes, so that, there will not be any contamination of the water source.
- Adoption of proper technologies for water supply.
- Adoption of proper water treatment technologies, so as to make the water bacterially free.

10.6.3.3 Agriculture

- Agriculture will be developed in the area.
- Increase in the commercial crops.
- Excess use of pesticides, insecticides and chemical manures

Mitigation Measures

- Better water management practices for agriculture like drip irrigation, sprinkling, and other water conservation high tech agro practices to decrease the risk of water logging.
- Rational use of pesticides and herbicides.
- Rationalization of agriculture crops.
- Better use of chemical fertilizers, pesticides and insecticides.

10.6.3.4 Health

- Increased incidence of vector borne and water borne diseases

Mitigation Measures

- Educate the rural population about the cause of diseases.
- Provide and improve the health facilities.
- Appropriate health regulations and enforcement.
- Timely provision of accessible health care including diagnosis and treatment
- Special disease control operations
- Individual protective measures.
- Educate the rural population regarding HIV-AIDS.
- Distribution of protective measures towards sexually transmitted diseases to the migrated labor at the construction site.
- By adopting proper treatment of bio-medical waste like incineration of gauze and organic waste.
- The sharps and needles to be disposed off properly and destroyed.

10.6.3.5 Ground Water

- Over exploitation of ground water for agricultural uses because of recharge of the ground water
- Pollution of ground water.
- Decrease in ground water table.
- Intensification of agriculture can lead to ground water pollution related to increased

Mitigation Measures

- Better recharge of the ground water, proper utilization of ground water.
- Regular monitoring of the ground water quality and measure the ground water table.
- Proper drainage system has to be devised so that the contamination kept to the minimum levels.
- Improving the rural sanitation would considerable improve the environment

10.6.3.6 Socio-Economic Impact

- The check dam project would give employment to locals during the construction stage.
- Increase agricultural productivity.

10.6.3.7 Solid Waste Management

The solid waste generated during construction work will be used for land fill because of the inert nature. The inert wastes mainly comprise of stones and rubble. The solid waste generated from the construction labor camp is mainly organic waste like vegetable peels, egg shells and polythene bags and mineral water bottles.

- Uncontrolled solid waste dump sites could be breeding ground for vermin's, and as such could pose a vector for diseases.
- Exposure of causal inhabitants to uncontrolled solid waste could result in injury or transmission of disease.

Mitigation Measures

- Door to door collection of waste or provision of community bins for waste collection.
- Segregation of waste depending on the nature of the material should be conducted. Special attention should be given to biomedical wastes for proper management in accordance with applicable regulatory requirements.
- Composting of appropriate organic wastes should be considered.
- Village councils and Water User Association could organize awareness programs for local population groups for the minimization and management of solid wastes. Local participation of the local community is a major condition for proper solid waste management.
- Trucks transporting the solid wastes should be properly covered.
- Land filling should be restricted to inert material only.
- The land fill sites and the access routes must be selected o minimize the impacts to the maximum extent possible. The land fill area should be away from the human habitation and water bodies. Special consideration for control of air emissions, odor, and contamination to ground water should be given if the solid waste is land disposed. Land disposal should be conducted at minimum in accordance with the best applicable local standards.

10.6.3.8 Plastic Waste Management

The solid waste should be segregated into recyclable wastes; inert wastes and plastic wastes .Most of the plastic resins can be recycled by applying steam, pressure and high heat. These separate most resins into monomers that can be refined and repolymerised. The awareness for recycling of plastic wastes in Yemen is not very high at this time. Unless a public awareness campaign can be mobilized to educate the people on the value of recycling solid plastic wastes, it is unlikely that this issue can be adequately addressed during the SBWMP.

10.6.3.9 Catchment Management

Putting up retaining walls at each of the terrace ends will prevent water from carrying silt into agricultural areas. It will also protect the agricultural farms. In addition to these benefits, the retaining walls will help in preventing soil erosion and silting of the reservoir. Wastewater from the agricultural fields can also be prevented from entering the wadi. By adopting a system of retaining walls, any reservoir water trapped behind the check dams will have the effects of fertilizers and pesticide waste mitigated to a certain degree. It also prevents the eutrophication of the reservoir waters. This would help in controlling the agricultural runoff.

Table 10.2 Environmental Matrix for a Dam Project indicating the Impacts

Environmental Parameters	Very Negative	Negative	No Impact	Positive	Very Positive
Construction Stage					
Soil Erosion		√			
Interference with Groundwater		√			
Raw material Handling		√			
Construction Equipments Handling		√			
Land acquisition and Resettlement		√			
Restriction to the Access		√			
Spoil of the Landscape		√			
Increase in Air Pollution	√				
Water Quality		√			
Agriculture			√		
Noise Levels		√			
Increase in Vibration		√			
Soil Quality			√		
Socio-Economic Status			√		
Solid Waste		√			
Access Roads		√			
Land Use		√			
Disturbance to Landscape		√			
Flora		√			
Health		√			
Increase in Waterborne Diseases	√				
Increase in Vector borne Diseases	√				
Construction Yard		V			
Storage of Raw Material		√			
Storage of Hazardous Material		√			
Construction Waste Disposal		√			
Labor Camp		√			
Mismanagement of Solid Waste	√				
Mismanagement of Wastewater	√				
Transport		√			
Operation Stage					
Air Pollution			√		
Groundwater				√	
Groundwater Quality		√			
Groundwater Table				√	
Agriculture Productivity					√
Noise Levels			√		

Socio-Economic Status					√
Diseases Incidence		√			
Markets					√
Migration for Better Future		√			
Health Facilities					√
Population Increase		√			
Connectivity					√
Agriculture Market					√
Solid Waste Management					√
Communication					√
Rural Sanitation					√
Agricultural Technologies					√
Agricultural Equipment					V
Post Harvesting facilities					√
Wastewater Technology				√	
Domestic Wastewater Treatment					√
Archeological Sites			√		
Catchments				√	
Soil Erosion			√		
Live stock					√
Agricultural Produce					√
Land Use Patter					√
Use of pesticides		√			
Use of Fertilizers		√			
Plastic Waste				√	
Domestic Waste Management					√
Village Infrastructure					√
Imparting Training					√
Temperature			√		
Rainfall			√		
Vegetation					√
Climate			√		
Road Network					√

10.7 Environmental Management Plan for Bahman Check Dams

10.7.1 Introduction

The proposed check dams would give rise to a number of positive impacts and will develop the rural economy to a great extent. The adverse impacts during the construction stage can be mitigated by implementing the mitigation measures at an appropriate time. The check dam would bring overall development of the rural area and will give an economic boost to the rural population. Suitable mitigation measures are suggested to curtail adverse impacts and implementation of the same is envisaged in the Environmental Management Plan.

The Environmental Management Plan, deals strictly with those actions needed to monitor and mitigate potential negative environmental impacts of the project The EMP has the following aspects:

1. Implementing the mitigation measures.
2. Monitoring the implementation program
3. Reporting to the designated institutions.
4. Training and capacity building
5. The budget for the mitigation measures.

10.7.2 Environmental Management Plan

An Environmental Management Plan is proposed for the design; construction and operation stages. The EMP should broadly discuss the following items:

- Adopting environmentally sound practices during the construction stage of the project.
- The waste material from site clearance will be disposed at suitable sites.
- The construction yards and labor camps will be provided with adequate water supply, sanitation, and first aid facilities.
- Efforts will be made to reduce noise levels from the construction equipment.
- Construction material and excess earth will be transported in spill proof trucks.
- Efforts will be made to prevent accidental spillage of oil and grease from construction equipment.
- The dust nuisance created by the excavation will be controlled by sprinkling of water.
- Proper management of the water resources.
- Adoption of better agricultural practices.
- Proper management of solid waste.

The matrix below provides the impacts caused by the dam project and the mitigation measures to be adopted. It also specifies the agencies responsible for the implementation and immediate action required. There are also certain mitigation measures suggested at the time of design, construction and operation stages of the project.

Table 10.3. Environmental Management Matrix

Issues	Impacts	Mitigation	Responsible organization to implement
Design Stage	**Input from Agencies**		
Public Participation	• Consult public, Water User Association and the Client • Consult the respective village groups	• Ensure local needs are anticipated and met. • Develop awareness	• PCU, Sana'a Basin Water Management Project • General Directorate of Irrigation (GDI) • National Water Resource Authority (NWRA)
Physical Environment	Review impacts of construction and facility operation. • Air quality • Water quality • Waste management • Health and safety	• Ensure that environmental factors are considered prior to construction • Builds awareness of potential environmental hazards and ways of preventing or mitigating them.	• PCU • GDI • NWRA
Socio-Economics	• Minimize disruption to facility operation during the construction • Minimize loss of land and property during construction	• Minimizes disruption during construction. • Minimizes socio-economic impacts during construction.	• PCU • GDI • NWRA

Issues	Impacts	Mitigation	Responsible organization to implement
Construction stage			
Dust and air pollution	• Construction activity • Transportation of material • Quarrying of construction material • Excavation	• Water sprinkling at the dust emission areas and at construction sites. • Sprinkling of water to suppress the dust • Development of vegetative cover to curtail air pollution.	• Engineer • Contractor • PCU • General Directorate of Irrigation
Water Pollution	Construction yards Labor camps	• Proper sanitation facilities at the labor camp. • Treatment facility for the domestic wastewater from the labor camps. • Treating wastewater from construction yard. • Provision of proper drainage channels to control runoff.	• Engineer • Contractor • Environmental Protection Agency • PCU • General Directorate of Irrigation
Construction Camp	• Solid waste generation. • Domestic waste water generation. • Incidence of water borne diseases	• Follow established housekeeping procedures. • Clean drinking water provision at the labor camps • Enforce sanitary conditions at the camp • Garbage collection and proper disposal • Medical aid availability.	• Contractor • Engineer • General Directorate of Irrigation
Noise levels	• Construction sites • Quarry sites • Construction machinery • Excavation activities • Transportation vehicles	• Work during daylight hours. • Laborers working in heavy noise generating areas will be provided with personal protective equipment (PPE)	• Engineer • Contractor • PCU • General Directorate of Irrigation

Issues	Impacts	Mitigation	Responsible organization to implement
Noise		• Construction machinery is properly tuned and greased. • Prohibit vehicle horns in village areas. • Blasting time will be carried out during the daytime hours, and only at the quarry sites. • Provision of noise barriers or enclosures	
Solid Waste	• Construction debris • Domestic waste	• Inert material will be used for the land fill. • The organic waste will be composted • The polythene and non degradable material will be disposed properly • Disposal of medical and hazardous waste	• Contractor • Engineer • PCU • General Directorate of Irrigation
Management of Construction Vehicle Access	• Ensure safety, erosion control and drainage. • Monitor condition of roads, available clearance for vehicles • Require contractor to repair damage to road network	• Suggest the proper mitigation measures to ensure safety and soil erosion	• PCU, Sana'a Basin Water Management Project • General Directorate of Irrigation • Local Council • Engineer

Issues	Impacts	Mitigation	Responsible organization to implement
Operational Stage			
Agriculture Development	• Excessive use of fertilizer and pesticides would affect the ground water resources. • Run off from the agricultural fields would pollute the near by water bodies. • Better agricultural productivity	• Rational use of pesticides and herbicides. • Conducting good agricultural practices. • Better water management • Awareness campaign to the farmers regarding agricultural farming practices, post-harvest technologies, and better management of existing water resources	• PCU • General Directorate of Irrigation • Local Councils • Water User Associations (WUAs)
Agricultural Markets	Generation of solid waste. • Incidence of diseases would increase among the rural population, because of the frequent visits of population from neighboring villages. • The farmer can sell his goods on a regular basis. • Increases in disease incidence due to the increase in the number of people visiting the market	• Better disposal practices adopted for solid waste generated at market areas. • Proper drainage at the market places to prevent water stagnation • Better sanitation facilities at the market places may reduce incidence of diseases	• Agricultural Cooperatives • Local Councils • WUAs
Health	• Increase in vector and water borne diseases due to the proposed project. • Generation of biomedical waste	• By adopting Proper treatment of bio-medical waste • Proper needle disposal • Available medical facilities • Adoption of better rural sanitation	• Public Awareness Outreach • GDI • WUAs • Local Councils

Water pollution	• Pollution water due to the lack of awareness • Ground water pollution & table	• Adopting better water management strategies • Monitoring the ground water table • Regular monitoring of ground water quality	• Public Awareness Outreach • GDI • WUAs • Local Councils
Wastewater	Generated from rural areas	• Treat wastewater generated • Assess physical, chemical, biological parameters.	• Public Awareness Outreach • GDI • WUAs • Local Councils

10.7.3 Training

Training will be imparted to the staff of the Project Implementation Unit at all levels to upgrade their capacity in the proper management of the check dams and will also be given a training in case of emergency, and the measures taken to handle emergency situations.

The training program will also include the use of pollution monitoring equipment and analysis techniques. The training will also include identifying and reporting of activities related to environmental pollution.

10.7.4 Budget

The budget is allocated in different items to the Project Implementation Unit. They are given in the following table.

Table 10.4. Budget Allocation

Sl. No	Accounting Categories	Budget Allocation to the Departments
1	Environmental Monitoring	PCU GDI
2	Budget for Comprehensive Sanitation Program	PCU
3	Mitigation Measures	GDI
4	Safety and Health	PCU
5	Environmental Training	PCU-Environmental Unit GDI-Environmental Unit Local Council
6	Environmental Awareness Program	PCU NWRA-Public Outreach Unit

Table 10.5 Initial Environmental Cost Estimates

Sl No	Environmental Enhancement Measures	Rate/Unit (In YR)	Number	Total Amount (YR)
1.	Initial cost for Low cost sanitation at the construction labor camp and construction of accommodation for labor.	1,500,000		
2.	Environmental Awareness for the labor and local population	500,000		
3.	Environmental Monitoring during the construction and operation stage of the project	5,000,000		
4.	Safe Disposal of sewage and waste.	250,000		
5.	Regular removal of water weeds from the reservoir	100,000		
6.	Protection measures against soil erosion	250,000		
7.	Provision of vegetative barrier surrounding the construction yard and labor camp	200,000		
8.	Dustbins and pits for Incineration or for safe disposal of solid wastes collected.	100,000		
9.	Provision of health facilities at the construction labor camp.	100,000		
10.	Organizing a Training Program for the PIU	100,000		

The rates quoted here are the approximate costs and the rates depend on the expenditure of the construction.

10.7.5 Environmental Monitoring

Environmental Monitoring will be carried out for various environmental parameters which include the water quality, soil quality, noise levels and ground water table and quality. Environmental monitoring during the construction stage and the frequency of sampling will be carried out once a week at the operational stage; it will be done once a month for all parameters. Awareness programs should be conducted with the participation of the Water User Association about the economical and environmentally responsible use of water.

10.8 Bahman Specific Environmental Issues

10.8.1 Solid Waste Disposal – Public Awareness

During site visits to Wadi Bahman, our teams observed that the villagers tend to utilize the wadi as a dumping ground. This practice will create problems in the future once the check dams are constructed. Solid wastes will degrade the quality of the water, become clogged in the check dams, and contribute to sediment build-up. Solid wastes may also inhibit the proper functioning of monitoring equipment (piezometers and the Parshall Flume); if the instrumentation is not kept clean of debris, data collection will become invalid and the use of Bahman as a pilot check dam project will be jeopardized.

Recommendation: As part of the Environmental Monitoring Program, public awareness about the function of the instruments, and the need to keep the wadi clean, should be a priority. The villagers who are interested in being trained in O&M should be educated on the importance of removing trash from the wadi on a regular basis. If a solid waste disposal plan does not yet exist for Wadi Bahman, a simple and effective plan should be create as part of the environmental effort for this dam project.

10.8.2 Access Roads

As noted in Section Three, the villagers in Wadi Bahman currently use the wadi bed as a means of traveling up and down the wadi. The construction of the check dams will most likely remove the access route through the wadi as a viable means of transportation.

The land use map shown at the end of Section Three identifies a number of farms along the sides of the wadi. It is likely that an access road of some kind will need to pass through farmland (or certainly near the farms). A route has not been selected at this time.

Access road routes near the wadi may result in collateral environmental damage in the wadi due to increased traffic near the wadi. This will certainly be less than the negative environmental impacts caused by traffic within the wadi itself.

Recommended Mitigation: Allow the local community to propose a viable access road through its properties. Local participation in construction of the access road could be obtained during the construction of the wadi. Environmental awareness of the impact of a road near the wadi should be transferred to the local villagers as part of the monitoring program. The contractors will need to provide access to all parts of the wadi during construction; it is possible that the contractors could provide the access road to the local groups as an incidental part of their construction activity in Wadi Bahman.

10.8.3 Trees in Wadi Bahman

A few trees have been identified in the wadi. These trees are not located near any of the proposed check dams and will not impact construction. The location of these trees can be found in Volume III, Drawings, BAH/PP/01 to 09.

Recommended Mitigation: These trees have survived the annual floods in the wadi, as well as traffic from local villagers. We can assume these trees are hardy and capable of withstanding changes in their environment. We recommend that the health of the trees is monitored as part of the monitoring program for the wadi. The performance of these trees could be used as a baseline to monitor trees located in future check dam projects. Additionally, the trees should be evaluated immediately after a storm event to see if they will be inundated by water retained in nearby check dams. It is unlikely that the water will harm the trees, and will most likely contribute to their health and growth.

10.8.4 Retention of Water behind Check Dams

The construction of twenty seven new check dams should result in significant improvement in the water availability in the Bahman area. Monitoring of the tube wells and bore wells in the area should be considered as part of the overall monitoring package. This would be in addition to the proposed instrumentation in the design, which includes the Parshall Flume and piezometers at each check dam. The monitoring of privately owned or collectively owned wells around Bahman Village is outside the scope of this recharge project. We would recommend that NWRA fund this additional instrumentation.

10.9 Annex : Terms of Reference, Environmental Assessment Study

10.9.1 Introduction

This section should state the purpose of terms of reference, identify the development project to be assessed, and explain the executing arrangements for the environmental assessment.

10.9.2 Background Information

Pertinent background for potential parties, who may conduct the environmental assessment, where they are consultants or government agencies, would include a brief description of the major components of the proposed project, a statement of need for it and the objective it is intended to meet, the implementing agency, a brief history of the project (including alternatives considered), its current status and timetable, and the identities of any associated projects. If there are other projects in progress or planned within the region which may complete for the same resources, they should also be identified here.

10.9.3 Objectives

This section will summarize the general scope of environmental assessment and discuss its timing in relation to the processes of the project preparation, design and execution.

10.9.4 Environmental Assessment

The Consultant responsible for the preparation of the Detailed EIA should follow a number of existing World Bank policies and guidelines.

In addition to the Yemeni Laws, the Detailed EIA will be prepared based on the World Bank guidelines viz. Operative Procedures (O.P) 4.01. A number of safeguard policies shall be adopted while preparing the report. The major policies which include the Environmental Assessment (O.P 4.01, Bank Procedures (BP) 4.01, GP 4.01), Pest Management (OP 4.09), Involuntary Resettlement (O.P/BP 4.12), Safety of Dams (O.P 4.37, BP 4.37), Cultural Property (OPN 11.03), Indigenous People (OD 4.20).

10.9.5 Study Area

The entire reservoir area to be studies considering the baseline environmental features, the solid waste management and the wastewater treatment technologies. The likely positive and negative impacts caused due to the proposed project on various environmental and social aspects will be listed and proper mitigation measures will be suggested. A social impact assessment will be conducted to assess the people reaction towards the project. The resettlement and rehabilitation plan will be drawn for the population who lost their land and property. A resettlement and rehabilitation action plan will be prepared. An environmental management plan will be designed fro the implementation of the mitigation measures.

10.9.6 Scope of work

In some cases, the tasks to be carried out by a consultant will be known with sufficient certainty to be specified completely in the terms of reference. In other cases, information deficiencies need to be alleviated or specialized fields studies or modeling activities performed to assess the impacts, and the consultants will be asked to define particular tasks in more detail for contracting agency review and approval.

10.9.7 Description of the Proposed Project

Provide full description of the project, using maps where necessary, and including the following information, location, general layout, size in terms of population and population equivalents, present and projected, anticipated waste water generated, construction activities, schedule, staffing and support facilities and services, operation and maintenance activities, staffing and support facilities and services, required off-site investments, life span.

10.9.8 Description of Environment

Physical Environment:

Geology (general description for overall study area, details for land application sites) soils (general description for overall study area details for land application sites) monthly average temperatures rainfall and runoff characteristics description of receiving water (identify of streams, ands its annual discharge or current data by month, chemical quality, existing discharges or withdrawals).

Biological environment:

terrestrial communities in areas affected by construction, facility, siting, land application or disposal, aquatic, estuarine or marine communities in affected waters, rare endangered species, sensitive habitats, including parks or preserves, significant natural sites, species of commercial importance in land application sites and receiving waters.

Socio-cultural Environment

Present and projected population, present land use planned development activities, community structure, present and projected employment by industrial category, distribution of income, goods and services, recreation, public health, cultural properties, tribal peoples, customs aspirations and attitudes.

10.9.9 Legislative and Regulatory Consideration

Describe the pertinent regulations and standards governing environmental quality, pollutant discharges to surface waters and land, water use, agricultural landscape, use of sludge, health and safety, protection of sensitive areas, protection of endangered species, siting, land use control etc., at international, national regional and local levels.

10.9.10 Determination of Potential Impacts of the Proposed Projects

Special attention to be given to:

- The water quality of the reservoir and its beneficial use to the community by the proposed dam.
- Projected quantitative changes in beneficial uses, such as fisheries, availability for drinking water and irrigation.
- Health impacts on the local population, like the vector and water borne diseases incidence and the frequency of incidence.
- Rural sanitation, agricultural markets and development of the area.
- Solid waste management.

10.9.11 Analysis of Alternatives to the Proposed Project

Describe alternatives that were examined in the course of developing the proposed project and identify other alternatives which would achieve the same objectives. The concept of alternatives extends to siting, design, technology selection, construction techniques and phasing, and operating and maintenance procedures. Compare alternatives in terms of potential environmental impacts, capital and operating costs, suitability under local conditions, and institutional, training and monitoring requirements. When describing the impacts, indicate which are irreversible or unavoidable and which can be mitigated. To the extent possible, quantify the costs and benefits of each alternative, incorporating the estimated costs of any associated mitigating measures. Include the alternatives of not constructing the project, in order to demonstrate environmental conditions with out it.

10.9.12 Development of Management Plan to Mitigate Negative Impacts

Recommend feasible and cost-effective measures to prevent or reduce significant negative impacts to acceptable levels. Estimate the impacts and cost of those measures, and of the institutional and training requirements to implement them. Consider compensation to affected parties for impacts which cannot be mitigated. Prepare a management plan including proposed work programs, budget estimates, scheduling, staffing and training requirements, and other necessary support services to implement the mitigating measures.

10.9.13 Identification of Institutional Needs to Implement Environmental Assessment Recommendation

Review the authority and capability of the institutions at local, provincial/regional, and national levels and recommended steps to strengthen or expand them so that the management and monitoring plans in the environmental assessment can be implemented. The recommendation may extend to the new laws and regulations, new agencies or agency functions, inter-sectoral arrangements, management procedures and training, staffing, operation and maintenance training, budgeting, and financial support.

10.9.14 Development of a Monitoring Plan

Prepare a detailed plan to monitor the implementation of mitigation measures and the impacts of the projects during construction and operation. Include in the plan an estimate of capital and operating costs and a description of the inputs (such as training and institutional strengthening) needed to carry it out.

10.9.15 Assist in Inter-Agency Coordination and Public/NGO Participation

Coordinating the environmental assessment with other government agencies; obtaining the views of local NGOs and affected groups; and in keeping records of meetings and other activities, communications, and comments and their disposition.

10.9.16 Report

The environmental assessment report should be concise and limited to significant environmental issues. The main text should focus on finding, conclusion and recommended actions, supported by summaries of the data collected and citations for any references used interpreting those data. Detailed or uninterrupted data are not appropriate in the main text and should be presented in appendices or a separate volume. Unpublished documents used in the assessment may not be readily available and should also be assembled in an appendix. Organize the environmental assessment report according to the outline below.

- Executive measures
- Policy, legal and administrative frame work
- Description of the proposed project
- Description of the environment
- Significant environmental impacts
- Analysis alternatives
- Mitigation management plan
- Environmental management and training
- Monitoring plan
- Inter-Agency and Public/NGO Involvement
- List of reference
- Appendices

    - List of Environmental Assessment Preparers
    - Records of Inter-Agency and Public/NGO Communications
    - Data and unpublished references.

10.9.17 Consulting Team

Core team: environmental engineer, environmental planner, specialist in ecology, water quality soil sciences, and sociology/anthropology.

Other specialties that may be needed, depending on the nature of the project are public health, agronomy, hydrology, land use planning, oceanography, water quality modeling and resource economics.

10.9.18 Schedule

Specify dates for progress reviews, interim and final reports, and other significant events.

10.9.19 Other Information

Examples are pre-feasibility studies, population and land use plans, ground water quality information, agricultural practices, water quality studies, and public health reports.

SECTION ELEVEN: SOCIAL ISSUES

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SECTION ELEVEN: SOCIAL ISSUES

11.1 Introduction

The present study focuses on a set of social issues that provide a clear picture of the overall socio-economic situation in selected villages/household clusters at the Bahman check dam site. The study is conducted within the framework of implementation of the Sana'a Basin Water Management Program. The Bahman Check Dam site is one of six targeted sites investigated under a project to complete Detailed Design and Tender Documents for Three Existing Dams and Three New Dams. The main tasks assigned to the social team were as follows:

- Conduct a review of previous reports and available documents in order to define any information gaps related to the socio-economic aspects that would be the basis for further implementation arrangements.
- Prepare a questionnaire and conduct dialogue with local communities for checking their willingness to work with the project
- Coordinate with other consultants under the SBWMP i.e. Demand Management Study and Environmental Impact Assessment (EIA) study.
- Conduct interviews with the relevant community groups in the field at the potential dam sites as part of a coordinated process for determining the willingness of the beneficiary communities to - participate in the project.
- Take full account of the communities concerned in the project. These communities are located upstream and downstream of the dam sites.
- Provide a clear picture of the social coherence at each dam site, how the communities are organized, and how the project could build upon existing organizations or create new types of organizations.
- Review and summarize past and on-going public awareness efforts with lessons learned from the SBWMP public awareness campaigns.
- Develop a public awareness campaign strategy and formulate detailed recommendations for sustaining and enhancing public awareness and support.

The total period devoted to the completion of the above mentioned tasks was more than three months including review of previous studies, collection of primary data, data analysis, conducting consultative workshops with community representatives and stakeholders, and report writing.

11.2 Background Information

In Yemen, surface water as well as groundwater is considered the main source of water used for different purposes, i.e. agriculture, industrial, and domestic purposes. Therefore, people in rural as well as in urban centers are heavily dependent on these sources of water. As population rapidly increases and industrial activities expand, the demand for water and its consumption increase resulting in severe surface and groundwater depletion. As indicated by water studies "*the estimated groundwater in Yemen is around 1000 MCM, which makes the total renewable water resource sum 2.500 MCM, while the total demand is estimated by 3,400MCM with 900 MCM deficit, which is covered from the deep aquifers*" (see Qahtan Yehya A.M. Al-Asbahi, 2005).

The per capita consumption of water in Yemen is estimated at about 143 cubic meter, which is a very low rate compared to other poor countries in the middle east such as Jordan where the rate is about 300 cubic meter (see Habib, 1996). This situation indicates that Yemen lives under a sever water poverty stress (Othman, 2005)

The Sana'a Basin that is located in the central highlands of Yemen with a total area of about 3112 km2 and a population of about 300 thousand inhabitants, is one of the areas affected by sever water crisis as it is considered one of the most heavily populated areas in the country. The poverty survey completed in 1999, found that in the Sana'a governorate, there is a considerable spread of poverty in the area as shown in table (1).

Table 11.1. Percentage of Poverty Spread between the Population Groups of Sana'a Governorate

% of population	% of poverty
26.3	< 10
31.6	10-19
5.3	20-29
15.8	30-39
21.0	40-49

Source: Ministry of Planning and Development, 1999.

The data show that about 42.1% of the population of the Sana'a Governorate live in very poor condition. This situation has affected the rate of illiteracy among people particularly women in the poor families, as studies have shown that about 90% of adult females and about 48% of adult males in poor families are illiterate.

In Nihm District where the Bahman check dam site is located, the demographic situation of the resident population can be evaluated to identify the number of families and households, and the average number of persons in each family and household. This information is expressed in Table 11.2.

Table 11.2. The Demographic Situation in Nihm District

Recent population			Number of households	Number of families	Average No. of persons/family	Average No. of persons/household
M	F	Total				
21,838	20,437	42,275	4,466	4,742	8.9	9.5

Source: Ministry of Planning and Development, 2004, primary results.

The water situation in the Sana'a Basin is getting worse, as water is continuously abstracted by all sectors of water consumption. The rate of the annual rainfall varies in the different districts of the basin between 50-500 mm. Moreover, over one million inhabitants depend on the same sources of the Sana'a Basin water. The population growth rate is also increasing; its growth rate is estimated at 3.5 – 4.1%. This results in an expectation that the population will double in the coming twenty years.

Agriculture is an important economic activity in the rural areas of the Sana'a Basin where cash crops, such as qat, grapes, and other trees, are the dominant crops in the area. It is therefore expected that agricultural irrigation as well as domestic use of water would, in one way or another, contribute to the increased water consumption and thus lead to a continuous environmental degradation in the different areas of the Sana'a Basin.

In order to counterbalance heavy water consumption, and to sustain an appropriate water management strategy, the government bank took the initiative to prepare a national water strategy and set up investment programs. This was accomplished with support from the World Bank. This led to the study of water basins with particular emphasis to the Sana'a Basin which is expected, as anticipated by previous studies, to be dried out within the coming ten years unless serious measures are taken into account.

One important step in overcoming water problems in the basin was the establishment of the Sana'a Basin Water Management Program (SBWMP) in 2004. The immediate objectives of the program are: 1) to increase both quantity and quality of the groundwater resources available for domestic and industrial use in the basin, and 2) to simultaneously increase the efficiency of agriculture water use so as to allow time for a gradual shift to a less water-based rural economy in the basin.

An overall indication of the different studies and reports concerning the characterisation of the Sana'a Basin area shows that the social project aspects were not given enough in-depth analysis. The first socio-economic study was the characterisation of the socio-economic situation in the area (*see Basin Characterization and Selection of Pilot Study Areas-Volume*

IV, Socio Economics, 2001). This study was followed by other technical studies that devoted some sections to comment on the socio-economic situation.

The above mentioned socio-economic study was carried out by Water and Environment Center of the Sana'a University. The study provided some important basic data about the socio economic system based on a Rapid Rural Appraisal (RRA) carried out in a short period. In the study there was a quantitative survey data analysis, with some qualitative investigation based on group discussions. Here, it could be indicated that some data requirements for building the social capital in addition to physical and human capital is important to be further investigated. This is important due to the fact that discovering self-initiative and social dynamics in the community would help approaching further implementation activities.

Before commenting on the information gaps of the socio-economic issue, we need to elaborate on the overall constraints affecting water management in the Sana'a Basin. This is important due to the fact that geological, hydrological and environmental issues are inter-linked with the social aspects especially when traditional and social complexities exist, as in rural areas of Yemen, as there are some differences in the systems of socio-political organization in the different targeted areas because of differences in education and openness to modern ideas.

The nature of constraints and water resources issues prevailing in the Sana'a Basin, based on the different reviewed reports, could be summarised as follows:

1- High water consumption for irrigation purposes is evident. This results in continuous and often uncontrolled water removal from private wells, resulting in an extensive decline in aquifer levels.
2- High water consumption for industrial (selling water to urban centers), domestic, and agricultural purposes.
3- Decrease of groundwater level by 4 meters/year, particularly in the 1980s and 1990s, as shown by previous studies.
4- Poor sanitation and water disposal, resulting in potentially widespread water-borne diseases as private water supply systems are not managed and monitored properly.
5- Disappearance of traditional water supply systems. Highly sophisticated drilling machines are now used to dig boreholes.
6- As groundwater levels continuously decrease, conflicts over water allocation between different water users become more frequent.
7- Low awareness levels among local communities about the importance of water conservation measures and policies has resulted in a growing water crisis.

It is worth mentioning that the above conclusions are not necessarily the same for all areas of the Sana'a Basin. This study would clarify the validity of the above mentioned conclusions.

In addition to the aforementioned documents, the feasibility study produced by Hydrosult in 2002 was also reviewed. These reviews focused on understanding the social and environmental analyses performed during these studies. The feasibility studies focused mainly on conducting topographic surveys, assessing access to dam sites, carrying out geological mapping, describing the hydrological aspects of existing structures, and investigation of geotechnical site conditions.

This study has led to the overall evaluation of dam stability and providing an overview of the results of the preliminary environmental impact assessment. Some social impacts in these studies were introduced in terms of quantitative indicators related to both environmental and social aspects. Table 11.3 summarises the situation in Bahman ,as categorised in the feasibility study.

Table 11.3. Summary of quantified SIA & EIA impacts (source Hydrosult, 2002)

Receptor Categories	Bahman
Man (settlement and infrastructure)	(o)
Man (agriculture on the sites)	(-)
Terrestrial Wildlife (animals and plants)	(o)
Aquatic Wildlife (animals and plants)	(o)
Soil	(+)
Water	(+++)
Cultural features	(o)
Additional water for domestic and irrigation uses	(+++)
Employment	(++)
Opportunities for water-based recreation at the reservoir	(+)
Lorry movements and construction processes	(-)
Inundation of irrigated land in the reservoir area	(-)
Potential inundation of unknown sites in the reservoir areas	(o)
Resettlement of family groups is required	(o)

(---) Extremely negative (+++) Extremely Positive (o) No effect

(--) Very negative (++) Very positive (-) Negative (+) positive

The above table provides some social and environmental impact indicators. These indicators reflect quantitative numbers and scales of the different measured and estimated effects of dam construction, for new or existing dams in the targeted areas. Although there are no qualitative in-depth explanations based on views of community members, the scaling confirms some of the findings concluded by the present social study. However, the social evaluation presented in this report has given more attention to an in-depth investigation of social aspects that are important to be reflected in the future awareness campaign strategy. Additionally, we recommend actions to be considered during this future campaign in order to maximise the benefits from any planned interventions.

11.3 Study Methodology

In order to fulfil the ultimate goal of the socio-economic study, which is to ensure community participation and sustain short-term and long-term public support during and after the implementation of the project, the following activities were performed.

11.3.1 Collection and Reviewing of Available Documents:

Several documents, mostly study reports prepared throughout the different phases of the Sana'a Basin Project in the years 2001 and 2002, i.e. identification and preparation periods, were collected and reviewed. The studies focused mostly on the characterisation of the Sana'a Basin area in terms of ecological, geological, hydrological, environmental, and socio-economical conditions. Preparation of the project components was also addressed. These studies were based on selected representative sites from the different districts of the Sana'a Basin (see the list of studies below).

Throughout the review process, more than 15 reports were reviewed. These reports allowed the social specialists to better understand the area and to identify information gaps for further investigation during this project.

In addition to the reports other secondary data concerning water conservation and other water issues were collected from different sources. These data sources included water policy papers, the Internet, and related institutions, such as the SBWMP Information and Public Awareness Campaign component.

In general, it could be indicated that previous studies provided quite a lot of information on the characterisation of the area in terms of geotechnical and ecological aspects. Some information on environmental and socio-economical aspects was also presented. However, to ensure successful implementation of the project there is a need for more in-depth investigation of important social and environmental issues. These issues include community structures, social dynamics, and interlinks between local communities and their local institutions, and between local communities and development agencies working in the area. In other words, more information was needed on understanding the basis for social capital, ensuring people's concerns were met, and enhancing their active participation in water conservation and water management development activities.

11.3.2 Preparation of the Work Plan:

During the review of documents and based on the assigned terms of reference, tentative work plans for the social experts were prepared and discussed with concerned officials.

11.3.3 Making Preliminary Field Visits to the Targeted Sites

Together with the international and local environmental experts and officials from SBWMP, preliminary field visits were made to the selected dam sites to interview community groups and make direct observations about the overall characteristics of the targeted communities. Based on the outcomes of preliminary visits and the intensive review of the collected documents, information gaps were identified. These gaps were addressed in follow-up data collection activities.

11.3.4 Preparation of Data Collection Tools

After the overall situation in the area was reviewed, the research methodology and data collection tools were prepared. The data collection tools included a questionnaire, or semi-structured interview schedule, for individual interviews, checklists for group interviews and focus group discussions, and guidelines for implementing participatory data collection tools. These tools included social and resource maps, and Venn diagrams for institutional relationships.

In order to ensure an in-depth investigation of the socio-economic aspects of the project, the study team adopted a triangulation process for data collection that went beyond quantitative survey data collection. This was accomplished through the use of different participatory data collection tools such as semi-structured individual interview forms/questionnaire, social and resource maps, Venn diagrams, key informants, and focus group discussions.

Social mapping and diagramming are considered important tools that give local people the opportunity to express and share their knowledge and experience through visualisation and close interaction. Visual methods are also important, as they give equal opportunity for all socio-economic classes and illiterate people to express their experiences about their area in an informal manner and short time.

At the outset of group interviews and discussions, participants from every local community are given a chance to draw a symbolic resource and social map about their area. Available resources and the distribution of households and social strata are sketched out on large papers attached to a wall. These groups are then asked to indicate available institutions and their relative power relations within the community. This is converted into a Venn diagram, or interlinked circles, representing the different institutions and their decision-making power.

Overall, the checklist prepared for guiding interviews and discussions reflected the important information about the different socio-economic aspects of the community. This information could be summarised in the following order:

- Basic data about the socio-economic characteristics of the six pilot areas, including Bahman.
- Mapping of available natural resources, social services, and opportunities of managing these resources and services from the point of view of the members of the local communities.
- The social structure and social status of different social categories within the studied community or area.
- The agricultural and non-agricultural economic activities in the studied communities.
- Analysis of social relations between the different social categories, and amongst the different villages. This analysis focused on prevailing social dynamics and conflicts among social groups--within and between villages.
- Analysis of institutional relations that reflect the boundaries and degree of decision making processes exercised by each institution found in the studied areas such as social figures, local non-governmental organizations (NGOs), cooperatives, local administrative councils, and local government.
- Analysis of gender rules and the position of women in accessing and controlling resources, services, and decision making processes.
- Analysis of the status, use, and management of water resources in the studied areas, including traditional and modern practices.
- Analysis of existing and expected constraints/negative effects as a result of constructing water dams in the studied areas as perceived by local people.
- Expected remedies and interventions as perceived by local people.
- Defining the existing and potential processes in the formation and functioning of water user associations in the studied areas.
- Evaluating the level of peoples' awareness on water conservation and the need and potential of awareness creation among rural communities.

11.3.5 Conducting Data Collection Visits

In order to implement the prepared participatory research methodology with its different tools, intensive data collection visits were made to the different selected sites in Bahman. Questionnaires were filled out and Participatory Rural Appraisal (PRA) techniques were conducted. An assistant team, consisting of two male and two female researchers, helped the socio-economic experts with filling out the questionnaires and notetaking during group interviews and focus group discussions. The members of this research team were selected from individuals experienced in dealing with PRA tools. Orientation training was provided to discuss the aims and objectives of the study, and to make the researchers aware of the study area and specific socio-economic research aspects.

The number of visited villages/clusters of households, the number of conducted individual interviews and focus group discussions, and the number of prepared social maps and Venn diagrams is shown in Table 11.4.

Table 11.4. Sample size and PRA techniques in Bahman Check Dam Site

Gender	No. of individual interviews/ forms	No. of group discussions	No. of maps/ diagrams
Male	12	2	2
Female	5	1	-
Total	**17**	**3**	**2**

Note: 2 villages were covered by the study

The number of interviewed individuals was selected based on random sampling procedures. Group discussions were carried out during the afternoon gatherings where people come together for qat-chewing sessions. In most of the group discussions, the research team informed people about the need to meet together in the afternoon to discuss about dams and related issues.

It is important to note that participatory and qualitative data collection tools were triangulated with semi-structured interviewing questionnaires. This allowed for quantified answers for some socio-economic data, and in-depth information for other social aspects. Triangulation was utilised through the cross-check of data from individual interviews, group discussions and direct observation. The importance of this triangulation of data and information sources is that it provides a wider perspective and validation of the collected results

It could be indicated that while socio-economic aspects in the prepared checklist were investigated in a similar manner for all six dam sites, special considerations were given to known differences between sites according to the nature of present and planned interventions. For example, where there are known, existing conflicts (Al Sinn and Al Jaef), more emphasis was given to determining the nature of these conflicts and understanding the alternatives identified by local people in solving these conflicts. Another example of conflict exists at Beryan, where there is a water user association that was established sometime in the past. Here, the experience of managing these associations could be investigated to find out about successes and weaknesses that could inform other experiences and actions to be taken in other areas.

11.3.6 Conducting Stakeholder Meetings

Several meetings with organisations/agencies involved in water conservation issues were made to collect secondary data, understand the performance of existing activities related to water management, cross-check collected information, study linkages and coordination efforts amongst the different stakeholders, and coordinate for further data gathering and situation analysis. This includes meetings with officials from the SBWMP, Ministry of Planning and Development, Ministry of Agriculture and Irrigation, and Ministry of Water and Environment.

Discussions with other project officers resulted in lessons learned regarding their experience in dealing with Water User Associations and public awareness campaigns. Another visit was paid to the Ministry of Agriculture and Irrigation (MAI), and the Irrigation Department. There, we met with Abdul Wahed Al-Hamdi, the head of the Dams Unit, and Mohamed Al-Iriani, the Assistant Deputy Minister for Irrigation. Several points were raised concerning links and coordination between the project and other related agencies. A visit was also paid to the Assistant Deputy Minister of Water. Some important points from this meeting included a discussion of the new national water strategy, and the new trends in water conservation.

11.3.7 Data Analysis and Writing Up

Data analysis included daily analysis and reporting, and it culminated in data tabulation and reporting. In this respect the members of the research team are asked to prepare daily reports with tentative conclusions and gaps in data collection for the aim of gaining further explanation from focus groups and individuals. Quantitative data were also tabulated and integrated with qualitative data in the final report.

11.3.8 Final Consultative Workshop – All Sites

After the collected data were analysed, a two-day consultative workshop was held in Sana'a. The main purpose of the workshop was to present the study methodology and tentative findings of the socio-economic study. In the first day of the workshop, community representatives and stakeholders from various development agencies were invited. The main issues discussed in this first day were the study methodology, the socio-economic situation in the study areas, community participation issues, and the status of community awareness on water conservation. This was followed by open discussion where feedback was received from all the participants. Community representatives provided only few comments and confirmed the main findings. In the second day, stakeholders from development agencies attended. The overall findings on socio-economic aspects, comments on the SBWMP public awareness program, and formation of water user associations were developed. Recommendations and follow up actions were presented and discussed.

11.4 Results and Discussions

The tabulated data from individual interviews was integrated with information from group discussions and direct observation to form the overall socio-economic reality in the studied area of Bahman dam site. A detailed description of the study outcomes for this project site is provided as follows:

11.4.1 General Socio-Economic Data and Services:

The Bahman Check Dam site is located in the Nihm District. Our visit was paid to Bahman village that is located on both sides of Wadi Bahman. We met the sheik of the village, Abdul Hamid Al-Moafa, who called upon many other people to participate in group discussions and individual interviews.

Most of the settlements found within Bahman are permanent housing structures, typically built from stones or concrete blocks. They consist of 2-5 rooms in a nuclear family house, and 4-10 rooms in extended family households.

Concerning household fuel, it was found that the most important sources of fuel are wood and
butane gas. Firewood is mostly foraged by women of the household. Use of butane gas as a source of energy has increased even though its price has increased in recent times.

The marital status of the surveyed persons in Bahman is recorded in Table 11.5 as follows:

Table 11.5 Marital Status in the Study Sample

	Married		Single		Widowed	
	Female	Male	Female	Male	Female	Male
No. of surveyed persons	5	10	-	2	-	-
% of total group, by sex	100	83.3		16.6		

All married individuals live either in their own households or in their father's households. The average number of family members of the surveyed sample in Bahman check dam site is 7 males and 5 females.

Concerning educational services in Bahman, it was found that there is one school in the area. It was constructed through a cooperative, local effort. The level of education among the members of the surveyed sample in Bahman is shown in Table 11.6.

Table 11.6 Educational Status in the Study Sample

Gender	Illiterate	Read & write	Basic	Intermediate	Secondary	Higher	total
Male	3	6	1	-	1	1	12
Female	4	1		-			5
Total	7	7	1	-	1	1	17
%	41.2	41.2	5.9		5.9	5.9	100

The above table shows that the rate of illiteracy is very high among the respondents. It reaches 80% between the surveyed women, while it reaches about 25% between the surveyed men. This is an indication of the low performance of educational services in the area. Moreover, males' enrollment seems to be higher than female enrolment in school. Combined male and female classes, difficulty in reaching schools, early marriage of girls, and prevalent negative attitudes toward girls' education, are among the important reasons for low female enrollment.

The availability of health facilities was widely acknowledged as insufficient. The number of health centers and health facilities is shown in Table 11.7.

Table 11.7 Health Center Status in the study area

No. of health centers	No. of doctors/nurses		Distance from village
	doctors	nurses	
1		1	1 km

Concerning health services in Bahman, it was found that there is one health center. Like the school, the health center was built as a local, cooperative project. One local person donated a house that is now used as the health center.

Sanitation is another issue that was given emphasis in data collection visits to the dam sites. The situation of sanitation in Bahman is shown below in Table 11.8.

Table 11.8 Sanitation Situation in the Study Sample

Situation	No. of persons	%	remarks
Sink holes	5	29.4	
Streets	12	70.6	
Total	**17**	**100**	

The sources of drinking water are also important. They can differ significantly from one area to another. There are four different sources of drinking water that were identified in the study sites. These sources are piped water, pore holes, surface wells, and water tanks. In Bahman, the respondents identified their source of drinking water in Table 11.9 below:

Table 11.9. Sources of Drinking Water in the Study Sample

Situation	No. of persons	%	remarks
Piped water	17	100	
Pore holes	-	-	
Surface water	-	-	
Water tanks	-	-	
Total	**17**	**100**	

The table shows that almost all the people in Bahman dam site have their own piped lines of water connected to their houses. The reason for this situation is due to the past intervention of the local sheikh. The sheikh closely followed the implementation of a rural water supply project, ensuring that most of the households in the village were connected to a water supply system.

Livelihood analysis is important in order to have a clear picture on the sources of income and the different ways of spending this income. Table 11.10 shows the livelihood analysis in Bahman dam site as follows:

Table 11.10. Livelihood Analysis in the Study Sample

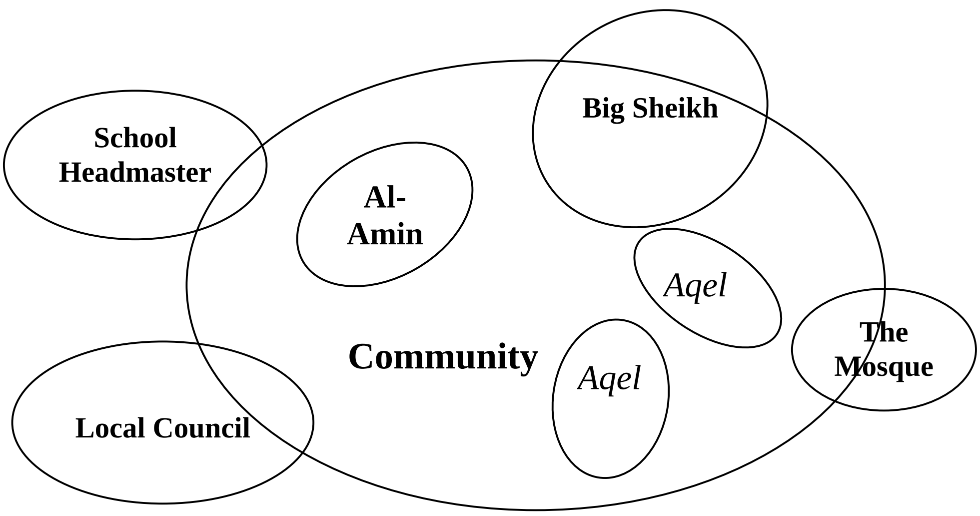
Sources of income		Sources of expenditure	
Source	%	Source	%
Agriculture	60-95	House needs	50-70
Livestock	5-10	Education	10-15
Jobs	5-30	Medicine	5-10
Other	20	Marriage of sons	10
		Agriculture Costs	10
		Buildings	10

The table shows that agriculture is the most important source of income in the Bahman villages, as the majority of households depend mainly upon the agricultural sector for their income. They also maintain some livestock, but not many. Other sources of income were working as lorry drivers, school teachers, and government staff.

11.4.2 Social Structure and Institutional Linkages

A tribal system is dominant in the Bahman area. This is very similar to the situations observed at other dam sites. At Bahman, the tribe is still considered as a political entity that plays an important role in the regulation of many of the public affairs, particularly those of social and political roots. Aqels and the big sheikh still hold considerable power in the cases of disputes. Individuals take their problems to their local Aqels or sheikhs, but they are also free to go to official local government representatives if part or all of the disputing parties are not satisfied with the solutions provided by their local sheik. It was noted that there are still some security and shared responsibility obligations evident in the Bahman community. These shared responsibilities include such items as blood money in the event of accidents, or other major offences that may still exist in the traditional tribal system.

Institutional Linkages & Decision Making Structure
Bahman Community



11.4.3 Land Use and Economic Activities

Most of the respondents living in the Bahman check dam site area own and operate their own private farms. but about 33.3% are sharecroppers and in the same time having their own private lands. Landholdings in Bahman were divided into three categories: small (less than one hectare); medium (1-2 hectares); and large (more than two hectares). Table 11.11 shows the results of the surveyed sample.

Table 11.11 Land Ownership Categories in the Study Sample

Area / Interviewed	Less than 1 ha	1 - 2 ha	More than 2 ha
No. of surveyed persons	5	4	3
%	41.7	33.3	25.0

From the above table, it is clear that most of the landholdings in the area are considered to be of small and medium size. Small landholdings seemed to be most common, as more than 30% of total respondents noted that their lands are less than half a hectare in size. Also, it was noticed that reclamation of new lands is a prevalent phenomena in the Bahman area. This is even more prevalent than the other five dam sites that are part of the Group A dam project. One respondent noted that his land area was expanded from 3.08 hectares to 4.4 hectares in few years. This indicates that some people are able to exert influence within the community as they convert Maraheq, or public lands, to private ownership.

As noted above in Table 11.10, people indicated that agriculture is their main source of income. A number of different crops are grown in the area such as grapes, qat, vegetables (tomato, onion, okra and garlic), and some fruit trees (peach and pomegranate). Vegetables are mostly grown in very small areas and they are often used for own home consumption. If rain is available, people will also grow barley and sorghum for their own home consumption.

One of the important findings in Bahman is that qat is mostly grown in Maraheq land; in the past, these common lands were used for livestock grazing. People indicated that in the past there were community collective norms that banned the use of Maraheq land for other purposes than grazing animals. Such norms have now disappeared due to the expansion of qat in the Yemeni culture. Converse to the growth of qat on public Maraheq land, grapes, an even more important crop in the Bahman area, are grown almost exclusively on private land.

Concerning credit and finance, about 83.3% of the respondents indicated that they used loans either from friends or from relatives. No one has indicated receiving loans from local traders or from a formal credit system. People who receive informal credit use the money to cover the cost of agricultural inputs and social obligations.

11.4.4 Gender Analysis:

The views of the women in the Bahman community were obtained from individuals as well as in group meetings held in different houses. Women as well as school girls participated in these meetings. It was noted that women play a major role in all of the activities in the households. They contribute to farming activities in addition to their role in caring for all family members.

Women in Bahman are active participants in agricultural production. They participate in planting, weeding, and harvesting of barley and sorghum. They also contribute in grape pruning, a skill that is passed down from mother to daughter. Table 11.12 shows gender roles in agriculture.

Table 11.12 Gender Role Analysis in the Study Sample

Activity	Women				Men			
	Qat	Grapes	Cereals	fruits	Qat	Grapes	Cereals	fruits
Cleaning fields	x	x	x	x	X	x	-	-
Land preparation	-	-	-	-	X	x	x	x
Apply fertilisers	-	-	x	-	X	x	-	x
Planting	-	-	-	-	X	x	x	x
Weeding	x	x	x	x	-	-	-	-
Irrigating	-	-	-	-	X	x	x	x
Apply pesticides	-	-	-	-	X	x	-	x
Harvesting	-	x	x	x	X	x	x	x
Transport harvest	-	-	x	x	X	x	x	x
Packing	-	x	x	x	x	x	-	x

Women's ability to participate in, and exercise power and control over resources, appeared to be minor in the communities.

11.4.5 Water Use and Water Management Issues

As indicated by the local people, there are three main sources of irrigation water--rainwater, surface wells, and pore holes. These sources, and there relative usage, is shown in Table 11.13 as follows:

Table 11.13 Irrigation Water Sources in the Study Sample

Source of water	No. of surveyed persons	%	Remarks
Rain	3	25	
Surface water	0	-	
borehole	9	75	
Total	12	100	

The table shows that ground water is most often extracted for use through boreholes. About six boreholes are found in the village, with depths that vary between 300-400 m. Local knowledge tells us that the wells have experienced an annual reduction in the water table level of approximately 5-6 meters. Surface water flows are found in the wadi branches, but many of the surface wells have dried up and no longer produce water.

In establishing their irrigation system, people indicated that about 18-20 persons come together as shareholders of one bore hole. They share the cost of digging, water pumps, water pipelines, and installation of the irrigation pump. The system is divided into a quota system where farmers either receive one day of pumping water every 18 days, or half of one day every 9 days. To manage their water distribution system, the farmers hire one person to organise and manage the system. This person receives about 80-100 thousand YR per year as a salary. When his turn comes to receive irrigation water, a shareholder has to bring his own diesel fuel. His contribution for oil must be provided in cash or in kind.

People indicated that no problems exist in managing the shared water distribution system. They have indicated that other problems exist such as social jealousy and revenge, rapid ground water depletion, and soil erosion when there are heavy rains.

When people's awareness on water use was investigated, it was found that most of the people in know about the problems of water depletion and about the Yemeni water law. Many of them, including the big sheikh, think that water law is a good thing if it is applied equally for all people. In the Bahman region, we found that some of the more powerful people will not obey this law, even if it is fairly applied.

The use of drip irrigation as an alternative irrigation method was also discussed. In Bahman, people indicated that prior to implementing a drip irrigation system, it must be tested in order to show its effectiveness to the population. Once people see the results of the drip irrigation, they will be convinced of the value of the system. They added that the cost of drip irrigation must be reasonable to encourage people to use the system after it proves economic and practical.

Other local initiatives include efforts by the sheikh to establish a water users association. It was also noticed that there are soil erosion problems in the wadi banks. People indicated that there is a need for soil protection techniques to be implemented in the area.

Concerning the expected benefit from a new dam, people believe that the presence of new check dams will solve the problem of soil erosion. Many of the interviewed people indicated that building check dams would benefit the area—resulting in increases in agricultural and livestock production as recharge of surface water takes place. They also expressed their willingness to construct one large dam in the upper Wadi Bahman region, as they believe more water could be stored and greater recharge would be likely.

11.4.6 Challenges and Opportunities

As indicated by people in Bahman, some social disorders and tribal revenge are the major social constraints affecting collaborative action by the villagers. The role played by the sheikh seems to be that of a conciliator, and he is active in resolving disputes. The sheikh, therefore, would be a key person in gaining support for any development activity. He could play an important role in facilitating the establishment of water user groups and in raising awareness about water conservation and water management practices.

11.5 Overall Conclusions

Based on the above discussions and outcomes of the individual interviews, the following overall conclusions can be made:

1. The use of participatory data collection techniques, and direct access to the community in coordination with development agents from SBWMP, has made the community free to express its views without influence from government officials and leaders. This influence was noted in previous studies.
2. High illiteracy rates, a rapid increase in population growth, and high levels of poverty are prevailing phenomena in the area. These phenomena contribute to a situation that has resulted in high water consumption and low response to development interventions.
3. Agriculture is an important economic activity in the area. It has resulted in heavy extraction of groundwater. Moreover, because of the lack of job opportunities in Sana'a, young people who finish their high school education go back to their villages and start investments in agriculture. This results in greater water consumption.
4. The availability of highly sophisticated equipment and machinery used for digging ground water wells has accelerated the competition to dig deep wells for irrigation of agriculture. The number of borehole wells has increased very rapidly during the past ten years.
5. Inadequate infrastructure and social services exist in Bahman area--except for electricity.
6. Expansion of cultivated lands on the Maraheq land is increasing, a situation that affect grazing lands and livestock rearing in the area.
7. Lack of hygiene, sanitation facilities and hygiene awareness exists in the community.
8. Lack of health facilities in the area.
9. There is no active role played by agricultural cooperative associations in the area. This is particularly true of old institutions that were established at the district level.
10. A low level of coordination exists between the community and development agencies related to water conservation. The recent exception can be found in some recent contacts made by SBWMP officials.
11. Lack of coordination between the different development agencies concerned with water conservation activities has affected the performance of planned interventions in rural areas.
12. Lack of a sense of ownership exists among the community people for dams that are constructed by the government. Most of the respondents expressed little or no sense that the dam 'belongs' to them. This situation, therefore, affects people's attitudes towards operation and maintenance of the dams. The same is true in people's attitudes towards the existing agricultural cooperative associations, as most of the interviewed people did not show that the institution represented a significant element of their life.

13. Although many people know about the problem of ground water depletion, no single action has been taken to overcome this problem. It was found that many people think that pumping water during the daytime is better for agriculture than pumping it during night time. This is one example about people's attitudes towards water use, which must be considered in any development intervention.
14. It was concluded that development agencies, in their interventions, focus more in building physical and to some extent human capital than building social capital. In this, it was noticed that social specialists are rarely found in the development agencies such as the Ministry of Agriculture and Irrigation and the Ministry of Water and Environment.
15. Scattered land holdings seem to affect the spread of new technologies regarding water conservation such as drip irrigation.
16. As noticed in the preparation of awareness campaign activities within SBWMP, most of the public awareness activities seemed to be budget-driven, rather than programme driven. Often, these programs are not gender oriented. The design of public awareness messages, sometimes begins before the outcomes of the situation analyses have been completed. Also, many designed messages are distributed to the concerned agencies without making sure that they reach the intended beneficiaries.
17. The role of agricultural extension services in the area is absent, although intensive agricultural activities are taking place.

11.6 Recommendations and Follow-up Actions

It is important to stress that recommendations and follow up actions will give more emphasis to building social capital among rural communities, as it proves to be important in accelerating development activities through active community participation. This does not, in any way, underestimate other development interventions such us technological and capacity building activities. Recommendation and follow up actions could be divided into the following subjects.

11.6.1 Public Awareness Campaigns:

The information and public awareness campaign work plan (IPAC) that was prepared in 2002 for SBWMP emphasised some important steps to be taken by the project. The efforts in implementing this plan should continue. However, some important considerations must be taken to improve the situation. These considerations could be presented as follows:

1- Considerations in preparation and implementation of awareness campaigns.

- The objectives of any public awareness campaign must be based on community needs and priorities. It is important to develop the objectives of any awareness campaign in a participatory way. It should start from drawing a problem tree, where people are encouraged to investigate the reasons and effects of any problem in water conservation and management. This practice will be helpful in identifying program objectives.
- It must be considered that changing people's attitudes and behaviours is not an easy process. It needs to be based on careful analysis of community norms and dynamics. This analysis must be supported by the skills of the development facilitators. Developing simple statements that help understand people's attitudes is important in evaluating progress in public awareness campaigning.
- Transparency in dealing with local communities, as well as face-to-face communication, is an important issue to be emphasised when preparing and implementing awareness campaigns.
- Segmentation of local communities into different groups, based on wealth and decision making influence, is important to insure a positive impact of the campaign.
- Multiplicity in communication channels and content is important to insure wider coverage and active community participation in awareness campaigns.
- More focus should be given to traditional events when conducting awareness campaigns. This could be social ceremonies, afternoon qat sessions, religious events, etc.

- Face-to-face communication should be followed in conducting awareness campaigns. Workshops and meetings outside the social realities of the communities proved ineffective in changing attitudes and behaviour.
- To develop a successful campaign, small and achievable activities should be developed at early stages of the campaign. This will provide early successes that can be built upon later in the campaign.
- Effective decision-makers must consider public awareness in their priority actions.
- Coordination between the different stakeholders is a must to insure complimentarily and future sustainability for awareness campaigns activities.

2- The sequence in the steps of preparation and implementation public awareness campaigns must be clear to the designers and facilitators. These could be specified as follows:

- Analysis of the present situation, which means careful study of community needs and interactions.
- Set the objectives of awareness campaign programme.
- Identify the type of the message to be designed.
- Design and test the applicability of the message and the communication channel in the local context.
- Select and train volunteer community facilitators on communication skills and management of public awareness campaigns.
- Set an integrated program on how to effectively communicate messages.
- Establish a data base system that came out of the regular monitoring and evaluation visits to the targeted areas.

3- In order to be effective, public awareness programmes must involve all development agencies working in the area such as:

- Sana'a Basin Water Management Project.
- General Directorate of Irrigation.
- National Authority of Water Resources.
- Water sector in the Ministry of Water and Environment.
- General Directorate of Agricultural Extension and Information.
- Extension and Rural Women Departments in Sana'a Agricultural Office and Northern Areas Rural Development Authority.
- Agricultural Research Station in the Northern Highlands.

11.6.2 Water Users Associations

1- It is important to start with community mobilization activities before the initiation of a WUA. This is important to prepare the intended community and raise their awareness on program objectives and the necessity of establishing a WUA. In one of the studied areas, Beryan, where the first WUA was established, it was found that people are not aware of why they have established their WUA. Some of them indicated that it was established to receive irrigation pipes from the donor agencies.

2- The local community groups who share boreholes in the studied areas could be a starting point for initiating WUAs at a village level.
3- Volunteer community facilitators must be selected from within an established WUA. But these individuals must be honest, trustworthy, educated, and supported by a majority of the surveyed people.
4- Members of WUA must be trained on communication and management aspects.
5- Start with small and achievable activities to build successes later on.
6- The period between initiating a WUA and launching its first activity must be as short as possible. People will become frustrated and give up on the WUA because of bad experiences with cooperatives in the past.
7- Creating sustainability in WUA activities should be considered right from the beginning.

11.6.3 Important Indicators in M&E of Public Awareness Programs

Either in measuring the impact of public awareness campaigning or in evaluating the success in capacity building and organisation of WUA, simple indicators that can reflect the results of these programs should be established. These could be a basis of a reasonable data base system, which would help creating progress according to continuous follow up activities. Some important progress indicators could be recommended as follows:

- Number of established WUAs.
- Number of the members in each WUA.
- Number of training and awareness creation events carried out by the program.
- Number of participants (males and females) in each training and awareness creation event.
- Changes that were recorded in the level of water use.
- Changes that were recorded in sanitation methods in the houses of rural communities.
- Number of self-initiated donations and contributions to the improvement of water conservation and management systems.
- Number of local community norms established in the community (e.g. banning of digging pore holes, use of proper sanitation methods, etc.).
- Increase or decrease of digging new surface and pore hole wells.
- Number of requests and pressure occasions but on government by local people in improving water conservation systems.
- Number of women who have benefited from training and development activities.
- Number of people that are able to recall 2-3 messages delivered to them on water conservation.

11.7 Support Photographs and Social Maps

Social and Resource Map drawn by Local People

Note: no camera was available during data collection visits to this area.

11.8 Annexes

11.8.1 Annex 1. List of Consulted Documents

1. Feasibility Study of Al Malah Dam, Hydrosult, July 2002
2. Feasibility Study of Bahman Check Dam, Hydrosult, July 2002
3. Feasibility Study of Al Sinn Dam, Hydrosult, July 2002
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11.8.2 Annex 2. Translated Interview Questionnaire

1. Name: ……………………………………….
2. Residency: Place of birth( ) Place of previous residence( ) Place of present residence( )
3. Age : (years)
4. Size of the family: Number of resident family members: ( ) Mother( ) Father( ) Brothers/sisters( ) Husband/wife( ) Sons( ) Daughters ( )
5. Work ability: Number of family members who can work:
   Men ( ) Women ( ) Youth ( )
6. Marital status: Single ( ) Married ( ) divorced ( ) Widow ( )
7. Educational status of family members:

   7.1- Number of children who go to school: Males ( ) Females ( )

   7.2- To which level girls are allowed to study:……………………………………

   7.3- What is the number of children who do not go to school: Males ( ) Females ( )

   7.4- What are the reasons for not going to school:

   - There are no schools in the area ( )
   - Schools are too far from village ( )
   - Inability to cover study expenses ( )
   - No benefit from education ( )
   - Gender mixed schools ( )
   - Other reasons? Please specify:

   7.5- Level of family members' education:

   Illiterate ( ) Can read only ( ) Can read and write ( )
   Primary school ( ) Secondary school ( ) University ( )

   7.6- If illiterate, read only, read and write

   – Do you attend literacy classes: Yes ( ) No ( )
   – Do you receive training in other fields including agriculture: Yes ( ) No ( )
8. Housing and sanitation:

   8.1- Is the house a private ownership: Yes ( ) No ( )

   8.2- Is it shared with other family members: Yes ( ) No ( )

   8.3- How many rooms are in the house ( )

   8.4- Is there a toilette in the house: Yes ( ) No ( )

   8.5- How used water is drained: Through a sewer ( ) To the street ( )

8.6- Do sewage water used for crop irrigation: Yes ( ) No ( )

8.7- Is drinking water connected to your house: Yes ( ) No ( )

8.8- If drinking water is not connected- which other sources do you use?

1) 2) 3) 4)

8.9- Is electricity connected to the house? Yes ( ) No ( )

8.10- Is there: Telephone line( ) Video( ) Radio ( ) Tape recorder ( ) TV ( )

9. Professional status:

9.1- Have you ever worked in the past?: Yes ( ) No ( )

9.2- What kind of work have you performed in the past?:

………………………………………….

9.3- Do you work now?: Yes ( ) No ( )

9.4- If yes-what kind of work you perform?: ………………………………………………….

9.5- Is the householder present in the village all over the year?: Yes ( ) No ( )

9.6- Do you work in your farm?: Yes( ) No ( )

9.7- Do you work in the farms of others?: Yes ( ) No ( )

9.8- Who usually work in the farm?: Man only ( ) Man and woman ( ) Woman and children ( )

9.9- Do you perform other job that give you extra income?: Yes ( ) No ( )
If yes- specify……………………………………………………

9.10- What type of work would you like to do in the future?: ………………………………………….

9.11- Why? Because it is profitable ( ) It gathers all family members ( )

9.12- Who takes care of the family?: The man ( ) The woman ( )

10. Agricultural properties and economic activities:

10.1- Total size of the farm ( ): Owned ( ) Rented ( ) Sharecropped ( ) Other ( ).

10.2- What agricultural crops do you grow?

Crop	Purpose of cultivation			
	Home consumption	Market sale	Animal feed	Other

10.3- Do you breed livestock?: Yes ( ) No ( )

Type of animal	Purpose of breeding	Ownership	
		Private ownership	Other

10.4- Other assets: Tractor( ) Irrigation pump( ) Well( ) Car( ) Big truck( ).

11. Gender roles

11.1- In agricultural practices

Role/activity	Cereals		Vegetables		Fruit trees		Qat		Fodder	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Cleaning fields from previous crop										
Ploughing										
Seeding/planting										
Irrigation										
Weeding/pruning										
Apply manure										
Apply chem. Fertiliser										
Spraying										
Harvest/picking										
Transport harvest from the field										
Threshing										
Sell main produce										
Sell secondary product										

11.2- In livestock breeding

Role/activity	Cows		Sheep		Goats		Camels	
	Male	Female	Male	Female	Male	Female	Male	Female
Bring fodder from the farm								
Cleaning stable								
Grazing animals								
Feeding animals								
Watering animals								
Milking animals								
Buy fodder								
Sell animals in the farm								
Sell animals in the market								
Sell animal products								
Inseminate animals								
Vet care								

11.3- In house keeping

Role/activity	Male	Female	Notes
Prepare food			
Take care of children			
Clean the house			
Wash cloths			
Fetch water			
Bring firewood			
Buy house needs			

11.4- Do children help in farming activities: Yes( ) No( )

11.5- If yes: During holidays( ) All over the year( ) Sometimes( )

12. Percentage of income sources:

- Agriculture ( )
- Animal breeding ( )

- Work in others' farms ( )
- Permanent job ( )
- Work outside the country ( )
- Other sources

13. Irrigation water and its uses:

13.1- What are the sources of irrigation water?

Shallow well ( ) Tube well ( ) Rain water ( ) Dam water ( ) spring water ( )

Have the area of your farm been changed during the last five years?

Increased ( ) Decreased ( ) Not changed ( )

13.2- If changed- what are the reasons?

13.3- What is the system followed now in irrigation water distribution?

13.4- Were there any changes as compared to the old systems? Yes( ) No( )

13.5- What are the changes if applicable?

13.6- If the source of irrigation water is a well or tube well:

- What type of ownership? Private ownership( ) Shareholding( ) Rent( )
- What is the depth of the well or tube well? (m)
- Do you pay to get irrigation water? Yes( ) No( )
- If you pay for water- how much is it in YR( )
- In case of shareholding- what is the size of you share( )
- In case of private ownership- do you sell water? Yes( ) No( )

13.7- If the source of irrigation water is a dam:

- What are the advantages of having a dam?
- What are the disadvantages of having a dam?

13.8- If there is no dam in the area:

- Are you in need of a new dam? Yes( ) No( )
- Do you think the new dam would benefit you and your area? Yes( ) No( )
- What would be the expected advantages of the new dam construction?
  - Increased agricultural production ( )
  - Expansion of Qat trade ( )
  - Growing of various group works ( )
  - Development of irrigation systems ( )
  - Organised crop rotation ( )
  - Attaining sustainable development ( )
- What would be the expected disadvantages of the new dam construction?

A number of orchards would be affected ( )

Disputes due to no compensations for affected lands ( )

Water seepage or leakage affecting crop production ( )

- In your view-who should pay the compensation for affected land?

  The government ( ) the public ( ) The local council ( )

- Who should pay the cost of operation and maintenance of the dam?

  Irrigation Department/MAI ( ) the public ( )

  Why do think so?

- How many labourers you think are needed for O&M of the dam(labour)
- How do you think they will be paid?

  All costs should be paid by local community ( ) Partial contribution ( )

- Have you ever paid any contribution in such cases? Yes( ) No( )
- In case you need money to contribute for dam O&M- where would you get it?

  From farming returns ( )

  By asking for a loan ( )

- Do you think dam O&M needs training and full time job? Yes( ) No.( )

  If yes- what kind of training?..

14. Agricultural marketing and processing:

14.1- Is there an organised market in the area where you sell your produce?

Yes( ) No( )

14.2- Do you market your produce in other areas? Yes( ) No( )

If yes- where?

14.3- How do you market your products?

Myself ( ) Through middlemen ( ) Others ( )

14.4- Is there available local transportation in the area for marketing your produce?

Yes( ) No( )

14.5- Do you have telecommunication facilities to help you market your produce?

Cable telephone ( ) Mobile phone ( ) Other means ( )

14.6- Do you dry grapes for making raisins? Yes( ) No( )

14.7- Are there other types of processing units for agricultural produce? Yes( ) No( )

15. Health and road services:

15.1- Is there health center in the area? Yes( ) No( )

15.2- If yes- How many doctors are there( ) How many health workers( )

15.3- If no-what is the distance to the nearest health center( )

15.4- What type of the available roads? Asphalt roads( ) Truck roads( )

15.5- Are there any nearby mineral-excavating business? Yes( ) No( )

16. Credit services:

16.1- Have you recently received or applies for credit? Yes( ) No( )

16.2- If yes- what are the source of credit you are dealing with?

Source/ Level	In cash	In kink	Remarks
The co-operative			
Agr. C. Bank			
Friends			
Relatives			
Traders			

16.3- Do you get credit to buy agricultural inputs such as?

Seeds ( ) Fertilisers( ) Pesticides( ) Other( )

16.4- Do you receive help from the agricultural credit bank on how to apply for credit?

Yes ( ) No ( )

17. Cooperatives and other community based organisations in the area:

17.1- Are there cooperatives/community based organisations in the area? Yes( ) No( )

17.2- If yes- are you member of these organisations? Yes( ) No( )

17.3- If yes- what kind of organisations and what type of membership?

Type of organisation	Ordinary member	Board member	Remarks

17.4- Is any one of your family a member of these organisations? Yes( ) No( )

17.5- If yes- are they males( ) Females ( )

17.6- What are the services you are now receiving from these organisations?

Organisation	Type of services

17.7- Are there public meetings held in the area to discuss common issues?

Yes( ) No( )

17.8- If yes- do women participate in such meetings? Yes( ) No( )

18. People access to and control over resources:

18.1- Access to and control over resources and services:

Resource	Access to (use of)		Control over (make decision)	
	Men	Women	Men	Women
Land				
Credit				
Extension services				
Agric. Inputs				
Machinery				
Means of transport				
Job or labour work				
Income from sales of agric. Crops				
Income from sales of animals/animal produce				

18.2- Decision making on important family issues?

Decision area	Man	Woman	Man's relatives	Woman's relatives	Remarks
Girls' marriage					
Boys' marriage					
Decide number of children					
Buy daily family needs					
Child health care					
Go to health centers					
Female employment					
Education & training					
Membership in community organisations					

SECTION TWELVE: MANAGEMENT FRAMEWORK IMPLEMENTATION

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SECTION TWELVE: MANAGEMENT FRAMEWORK IMPLEMENTATION

12.1 Section Summary

This section identifies the key issues surrounding the procurement and management of construction efforts at the six dams identified in Stanley Consultants' scope of the Sana'a Basin Water Management Program (SBWMP) Component 2 works. Procurement and bidding document issues are described, as are a general discussion of cost escalation and contingencies that must be considered during project implementation. Several critical issues that may impact the timing and success of construction are also discussed within this section.

Land acquisition was not envisioned at the beginning of the SBWMP; in the three years that have passed since the program began, farmers have developed agricultural fields and homesteads in sensitive areas at several dam sites.

The timing of construction is important. The rainy season in Yemen begins in mid-March and lasts until mid-May; it begins again in mid-July and continues through mid-September. The integrity of an incomplete dam body can be severely impacted if floodwaters are allowed to penetrate the construction works. Diversion works to protect under-construction dams may also be prohibitively expensive. For this reason, timing to construct vulnerable works in the dams should be carefully considered by the PCU and GDI.

Cost escalation prior to and during construction can also impact the management of the construction program. Worldwide prices for commodities such as cement, steel and fuel have risen sharply in the past several years. Surcharges on project construction works have been mandated by the Government of Yemen since July 2005. As pressure continues to drive up the cost of these basic items, the construction cost of the dams could increase.

Post-construction monitoring of the performance of each dam will also play a vital role in evaluation of the success of this program component. Execution of monitoring programs is discussed in separate Monitoring Plans for each dam.

12.2 General Procurement

Component 2 of the proposed credit for the SBWMP involves the rehabilitation and new construction of fifteen dams within the Sana'a Basin. The procurement of goods and services for the construction of Component 2 will be carried out as described in the Project Appraisal Document date April 23, 2003. As identified in the PAD, procurement of these services should be carried out in accordance with the *Guidelines for Procurement under IBRD Loans and Credit,* January *1995,* revised January and August *1996,* September *1997* and January *1999.*

Pre-qualification of contractors will be needed for all contracts valued at above $1 million USD, or its equivalent, which are procured under NCB procedures. All contracts procured through ICB procedures will also require prequalification.

National Competitive Bidding (NCB) will be utilized for civil works with estimated values below $2.0 million. Simplified NCB documents would also be prepared for use under the Credit and apply to relatively low-value works contracts. Should larger packages be considered by the PCU and GDI (over $2 million USD), they must be procured using ICB procedures and documents and advertised in UNDB and in local newspapers.

The NCB procedures will be advertised locally and carried out in accordance with GOY procurement laws and regulations that are acceptable to the Bank. Additional requirements include sufficient time for bidders to submit bids (4 weeks minimum); clearly specified evaluation and qualification procedures; no margin of preference to domestic contractors; eligible firms are allowed to participate; bids are not rejected during the bid opening; and that awards are made to the lowest evaluated bidder that meets the required standard of capability and resources. NCB procured contracts will be advertised in at least two local newspapers. NCB contracts would be open to eligible foreign bidders.

Should the size of the dam packages be increased to the ICB threshold, the following procedures will apply. Standard IDA prequalification documents will be used. Yemeni contractors competing under ICB procedures would receive a bid evaluation preference of 7.5 percent in accordance with Bank Guidelines.

12.3 Procurement Activities of Yemeni Government

As identified in the PAD, public procurement in Yemen is regulated by the principles set out under Law No. 3 of 1997 and Decree No. 234 of the same year. Under this decree, contracts for consultancy services and construction are reviewed and approved by the Supreme Government Auctions and Tender Committee, also called the High Tender Board (HTB). While open tender is assumed to be the GOY's preferred procurement method, large contracts are often split into smaller contracts that may fall under the HTB review level.

HTB review can be a lengthy process, especially for larger contracts. The size of the contracts envisioned under Component 2 is expected to be below $2 million for each dam package. PCU and GDI should consider the amount of time required for HTB review of dam construction packages that will be awarded to contractors. Delays in the HTB review period could impact the construction schedule of the dams.

12.4 Schedule of Procurement

In the PAD, the fifteen dams were split into two subcomponents – rehabilitation of eleven existing dams (Component 2A), and construction of four new dams (Component 2B). The original vision for completion of construction activities on these 15 dams was for each component to be realized in a three year cycle. The highest priority dams would be completed in Year One, and the lessons learned and knowledge gained can be applied to dams in Years Two and Three.

The current arranging for packaging dams may easily fit into this program. According to the PCU and GDI, five packages of three dams each are envisioned for procurement (see section 12.5). If one dam is completed during each Year of the program, a contractor will be able to focus his efforts on one project each year. The lessons learned from the first work can be applied to the later dams.

In accordance with the PAD, pre-qualification will be necessary for each dam package. The time required for prequalification should be taken into account when the procurement procedure is initiated.

The following general activities will take place within the periods for prequalification, bidding and selection of the winning contractor for award, negotiations and construction:

Prequalification	Issue of Notice / Advertisement
	Submission of Prequalification by Contractors
	Review of Prequalification Documents
	Preparation of Bid List
	Approval of Bid List
Bidding Process	Issue Bidding Documents
	Submission of Bids by Contractors
	Bid Evaluation
	Selection of Contractor
	Review of Bids by High Tender Board
	Issue of Letter of Acceptance
	Contract Negotiation and Signing
	Submission of Performance Security
	Notice to Proceed / Site Handover Date
Mobilization	Contractor Mobilization
Construction	Construction
	Completion Date
Defect Liability	Completion of 365 day period
	Issue Defect Liability Certificate

12.5 Dam Bid Packaging

Apart from the six dams included in Stanley Consultants scope of works, SBWMP includes the construction of Shi'b Al-Ma'adi Dam and rehabilitation of another eight dams. Works pertaining to these dams are designed by other consultants.

During progress meetings with the Project Coordination Unit (PCU) of the Ministry of Water and Environment, and the General Directorate of Irrigation (GDI), agreement was reached on the packaging of the dams. Each package will consist of three dams – one new dam and two rehabilitated dams. The bidding documents for each dam have been developed separately to allow PCU maximum flexibility should these bid packages be changed.
The envisioned packaging of the dams is as follows:

Table 12.1 Organization of Bid Packages

Package Number	Dams in Bid Package
1	**Beryan**, Al Lujma and Tozan
2	Al Masham, Al Arisha, and Al Hayathem
3	**Shib al Ma'adi**, Eial Hussein and Bani Naji
4	Thumah, Al Jaef and **Bahman**
5	Mahalli, **Al Sinn**, and **Al Malah**

New dams are identified in bold type.

The PCU, GDI, and the technical advisory consultant to the PCU (Arcadis Euroconsult, or AEC) may wish to consider the following items as the bid packages are finalized. It is possible that efficiencies in cost may be obtained by creating bid packages with dams that are compatible or require the contractor to perform similar services. These efficiencies might be realized if the contractor is required to complete more than one dam simultaneously. If the packages are designed to be completed over a three-year period (one dam per year), it is unlikely that these efficiencies can be realized. These items are listed in order of potential effectiveness.

1. **Location**. Dams that are located near each other may allow a contractor to provide co-locate his resources. This could be realized through the provision of fewer (but larger) work camps; co-located staging areas for materials and disposal sites; and reduced hauling distances to common borrow areas. The environmental impacts of co-located areas should be considered before a decision is made in this regard.
2. **Similar Dam Types**. Bid packages that contain all earthfill dams, for example, may allow a contractor to realize efficiencies in his ability to complete the works. He may be able to reduce his costs of material acquisition through the purchase of materials in large quantities for multiple sites. Work crews will gain experience in dam construction through repeating similar tasks during construction at multiple sites.
3. **Timing of Construction**. The schedules for construction of each dam will vary. Reasons for this include the rehabilitation and construction works to be completed;

and the urgency to protect new construction works from rainy season floodwaters. PCU and GDI may wish to require contractors to provide a consolidated construction plan as part of their bids. This will show PCU and GDI that a contractor understands the importance of scheduling his work around the following activities: mobilization; resource allocation; and the rainy season constraints.

4. **Supervision.** AEC and GDI will be responsible for supervision of the construction. If the dam works in a bid package are spread across the Sana'a Basin, it will be difficult to provide regular site supervision unless personnel are located full-time at each site.
5. **Site Investigations**. Some dam sites may require the contractor to perform additional site investigations during construction. These investigations are provided for as Provisional Sums in the Bills of Quantities. If a bid package requires investigations at all dam sites, the contractor will most likely procure services through a single source. The subcontractor responsible for these services will be able to realize some efficiencies and reduce his costs. Additionally, the investigations are more likely to be standardized when a single subcontractor performs investigations at multiple sites. If each dam package requires investigation services at one site, there will be inevitable competition between the construction contractors for these services. This may drive up prices for the services.

12.6 Bid Documents

The Standard Bidding Documents issued by the World Bank in 2002, and revised in 2003, have been utilized as the basis for all contracts. Use of these documents was coordinated with PCU and GDI directives, as well as review and comments from AEC. The documents used for all dam contracts are the *Standard Documents for Procurement of Works on Smaller Contracts*. Changes have been made in coordination with PCU to incorporate local conditions and requirements.

Additional directives from the PCU included use of the previously prepared Irrigation Improvement Project bidding documents from 2004. These bidding documents have been approved by the World Bank and are based upon the same Standard Document noted above.

The Bidding Documents have been prepared for each of the six dam sites. The following sections are provided in each document. Contract Documents may be amended by the Employer through Addenda issued during the procurement process. The separate nature of each document provides PCU and GDI with flexibility in modifying the dam bidding packages to suit their requirements.

Volume One

Section I	Invitation for Bids
Section II	Instructions to Bidders
Section III	Forms of Bid and Qualification Information
Section IV	Conditions of Contract
Section V	Contract Data
Section VI	Specifications
Section VII	Drawings
Section VIII	Bill of Quantities
Section IX	Forms of Securities

Volume Two

Specifications

Volume Three

Drawings

12.7 Critical Procurement Issues

12.7.1 Land Acquisition

As described in the PAD, no land acquisition or involuntary resettlement was envisioned at the time of Project Approval. Three years have passed since the PAD was published. The settlement and land use at some dam sites has changed considerably since that time.

Reservoir areas upstream of the new dam sites have been acquired for use by local farmers. At some locations, new agricultural fields of qat and grapes have been identified. It will be necessary for the PCU, GDI, and other supervisory organizations responsible for the SBWMP to resolve the land use and land access rights of farmers. Some of these farmers have been cultivating crops in areas that will be impacted by construction of the dams for two or three years.

GDI has been utilizing a demand-based approach to land acquisition for dam construction since 1994. This procedure is described in the PAD. In summary, it requires communities to sign contracts with GDI and to provide the land for the dam (and conceivably the reservoir as well) as a contribution to construction. The communities are then responsible for compensating individuals who will lose the use of inundated lands. While this procedure shifts responsibility to the local community, GDI and the PCU will have to confirm that all land agreements are in place before procurement and construction activities begin. The nature of the rainy season in Yemen requires that new dam bodies are protected from floodwaters during construction. This is doubly important because no diversion works have been designed into the projects in order to keep construction costs low. Careful planning of the timing for beginning each dam project will be needed.

12.7.2 Timing of Construction / Construction Program

As mentioned earlier, the timing of procurement and construction should be coordinated closely with the rainy seasons in Yemen. This is most important for new constructions, as the dam bodies and filter zones will be exposed prior to completion of the outer dam layers. Floodwaters may enter unprotected dam bodies during a storm event, which would compromise the integrity of the construction and delay the works. Diversion works may not be feasible for the dam sites, as the cost of these works could substantially increase the overall cost of the dam. Therefore, careful planning is seen as the best solution to this issue.

In addition to the timing of construction, performance periods for the works must be based upon the perceived difficulty of the work at each site, requirements for mobilization, and the capability of contractors likely to bid upon the works. The construction program for the dam at Al Sinn is given in Section 15.

Table 12.2 identifies the differences in construction timing and duration for existing rehabilitations and new constructions. It is reasonable to assume that the starting dates for dams in the other part of Component 2 will have similar starting dates.

Table 12.2 Construction Periods for Each Dam.

Dam	**Rehabilitation or Construction**	**Construction Period**	**Start Date**
Beryan	Construction	420 days	August
Bahman	Construction of Check Dams	180 days	August
Al Malah	Construction	360 days	August
Al Sinn	Construction	360 days	August
Al Lujma	Rehabilitation	150 days	August
Al Jaef	Rehabilitation	150 days	August

12.7.3 Cost Escalation

One of the issues that will impact the execution of the implementation of dam works under SBWMP is the increasing costs of basic commodities required for the construction of the dams. Three of these commodities that may impact the costs of dam implementation include cement, fuel, and steel. Worldwide construction activity has been on an upswing since 2002. Demand for cement has increased around the world, as concrete is a basic component of nearly all civil and building works. The impact that these prices increases will have upon the procurement process is significant. Accurate cost estimates are needed in order to properly evaluate the contractor bids.

Table 12.3 identifies the impact of the cost increases of cement, steel and fuel over the previous three years. It is reasonable to assume that some amount of increase will continue before construction and rehabilitation of all dams is complete.

Table 12.3 Commodity Price Increases.

Material	**Cement**		**Steel**		**Fuel**	
Year Priced	Price in YR/bag	Escalation to 2006	Price in YR/ton	Escalation to 2006	Price in YR/liter	Escalation to 2006
2006	1,400	0%	95,000	0%	60	0%
2005	1,200	17%	95,000	0%	60	0%
2004	850	65%	85,000	12%	35	71%
2003	650	115%	65,000	46%	35	71%

In July 2005, the GOY issued a decree that all construction contracts would have additional compensation to contractors levied upon them to compensate for increased costs. An 8% fuel compensation increase was issued for all construction contract line items, as GOY had decreased the fuel subsidy in Yemen at the same time. This resulted in a sharp increase of fuel cost throughout Yemen. Additionally, all cement-based Bill of Quantity construction items were allowed a 3% increase in compensation due to worldwide price increases in cement. These increases were applied to all contracts underway at the time of the decree. Contracts that had not been procured as of July 2005 were not subject to this escalation.

It is possible that similar compensation increases may be issued by GOY during the planned three year execution period for construction. This is especially true if material costs continue to rise due to global demand for cement, fuel and steel. Appropriate contingencies should be made by PCU in order to have funds available for contractors should GOY issue a similar compensation degree before 2009.

12.7.4 Post Construction Monitoring

Monitoring of the dams' performance will be important to evaluation of the SBWMP success. The data gathered during monitoring will allow GDI and PCU to evaluate the recharge generated by the dams. This may be especially important at a check dam site such as Bahman. Recent research and evaluation of groundwater in the Sana'a Basin (Foster, 2003) has resulted in recommendations that check dams may be the most appropriate structures for future recharge schemes. Dam monitoring will also be important to the safety of population groups living downstream of the dam sites.

Discussion of the monitoring programs for each dam can be found in the separate Monitoring Plan.

12.8 General Rehabilitation Works

The primary rehabilitation activities at the Bahman Check Dams include the following works:

- Construction of 26 new check dams.
- Installation of piezometers at each dam.
- Construction and calibration of a Parshall Flume.

Due to the relatively high number of the check dams which will be part of the works, with small heights and subsequently small volume of construction material, it is recommended that the contractor begin his works from the center area of the wadi. Two separate construction teams should be employed. One should move upstream and finish works while moving towards the head of the check dams, while the second team should move downstream towards check dam HV. Therefore, the Contractor and the Engineer camps should be located out side the wadi as close as possible to the center of the working zone.

12.9 Schedule of Procurement and Construction

Figure 12.1 identifies a proposed schedule for the prequalification and procurement of construction services, and for the construction at the Bahman Check Dams. The timing of events is very critical to the success of the project.

The prequalification process will be important to identifying the most qualified, available contractors to complete the fifteen dam construction and rehabilitation programs under SBWMP Component 2.

There are a few tasks in the procurement phase of the works that could be delayed if the PCU is not vigilant in adhering to the recommended schedule. The PCU should be aware of the possibility of delay during these activities. It is recommended that they should take actions to ensure that these tasks are completed in a timely manner so as not to delay the procurement and construction process.

12.9.1 Review of Bids

This activity is entirely within the control of the PCU. The review of construction bids must be completed according to pre-established guidelines, and in a fair and accurate manner. We suggest a period of one month to complete reviews of the contractors' bids if the single construction package for Bahman is considered. The review committee must be available throughout this period so that a proper bid evaluation and recommendation for award can be made at the end of the period.

If the technical assistance consultant AEC is able to be involved in the bid evaluation process, this will help PCU with review of all construction bid packages.

12.9.2 Review by High Tender Committee

The review time by the High Tender Committee (HTC) is outside the direct control of the PCU. It is possible that the review could take two or three months, or even longer, if the construction contracts are not pushed through the HTC review process. It will be very important to keep the HTC review and approval period as short as possible in order to maintain the construction schedule during the dry season. A finding of "No Objection" by the World Bank should be obtained as soon as possible after the HTC has approved the recommendation of award.

12.9.3 Award, Negotiation and Notice to Proceed

Once the recommended contractor has been approved for award, the PCU should work to begin negotiations with the contractor. If the procurement has moved forward according to schedule, this will occur in the spring. Additional time has been built into the procurement schedule for issuing the Letter of Acceptance, receiving the performance bond from the contractor, and signature of the contract. This duration of these activities is anticipated at three months, and delays from earlier steps of the procurement process can be covered by this period.

12.9.4 Commencement of the Works

In order for the contractor to complete the construction works at Bahman during the dry season, he must begin the works in August. See Figure 12.1. Mobilization is anticipated to be complete within a two week-long period. There will be several weeks between negotiations and Notice to Proceed; the contractor can take advantage of this period by evaluating the site, organizing his resources, and confirming the suitability of site access and material availability.

The upstream dam works, which include construction of a new reinforced concrete wall and a grouting program at the upstream face of the dam body, represent the greatest risk to the project. It is imperative that these works are completed during the dry season. Diversion works have not been included in the scope of design works, as they would substantially increase the overall cost of the project. The dry season in Yemen begins in August and runs until mid-March. The project has been scheduled in such a manner that the contractor should be able to complete all project works within the construction period.

12.9.5 Multiple Work Crews – Scheduling

As mentioned earlier, it is recommended that the contractor begin with two separate work crews, each working outwards from the midpoint of Wadi Bahman. A third crew could be utilized specifically to install the instrumentation at each dam. The schedule shown in Figure 12.1 assumes that this third crew will work alongside the check dam construction teams, installing piezometers as check dams are completed. Alternately, the contractor could choose to install piezometers after all check dams have been completed. If this occurs, the contractor will most likely require six weeks to install the 26 piezometers.

12.10 Special Site Issues

12.10.1 Access Roads

The wadi is currently used as a method of accessing villages and farms all along the wadi. Creation of an access road will be necessary in order to provide post-construction site access for the local residents. It will be possible to require the contractor to provide site access during his construction activities. This construction access road should be determined in conjunction with the local authorities and sheikh so that it may be utilized after the check dams are completed.

12.10.2 Local Labor Force

The local communities around Bahman are willing and ready to provide labor for construction of new check dams. They are also very willing to be trained in operation and maintenance of the check dams. The willingness of these communities to assist in dam O&M will be helpful in monitoring of the check dam performance. Close coordination with the sheikh and Aqids in the Bahman community will gain goodwill for the contractor, the PCU, and the Engineer's representatives who work on the project site.

12.10.3 Monitoring – Pilot Program

The separate monitoring program contains more information regarding the Monitoring Program for the Bahman Check Dams. This dam site should be considered as a pilot program for other check dams that may be implemented in the Sana'a Basin, and elsewhere in Yemen. The primary issue of importance to note here is that the monitoring and data collection program must be implemented. Without solid, consistent data, it will not be possible to properly evaluate the usefulness of the check dams in recharging the groundwater aquifer.

ID	Task Name	Start	Finish
1	**Prequalification Process**	**Sat 7/1/06**	**Sat 9/30/06**
2	Prepare Prequalification Documents	Sat 7/1/06	Sat 7/15/06
3	Approval by World Bank	Sun 7/16/06	Sun 7/23/06
4	Issue Prequalification Notification	Mon 7/24/06	Mon 7/24/06
5	Submission of Documents	Mon 7/24/06	Tue 8/15/06
6	Evaluation Submission	Wed 8/16/06	Thu 9/7/06
7	Approval of Bid List	Sat 9/9/06	Sat 9/23/06
8	No Objection to Bid List by World Bank	Sun 9/24/06	Sat 9/30/06
9			
10	**Bidding Process**	**Sun 10/1/06**	**Wed 8/1/07**
11	Issue Bidding Documents	Sun 10/1/06	Sun 10/1/06
12	Preparation of Bids	Sun 10/1/06	Thu 11/30/06
13	Submission of Bids	Thu 11/30/06	Thu 11/30/06
14	Bid Evaluation	Sat 12/2/06	Wed 1/31/07
15	Approval of Bid Report	Thu 2/1/07	Wed 2/28/07
16	No Objection to Bid Report by World Bank	Thu 3/1/07	Thu 3/15/07
17	Contract Negotiations	Sat 3/17/07	Sun 4/15/07
18	Issue Letter of Acceptance	Mon 4/16/07	Mon 4/16/07
19	Submission of Performance Bond	Sat 6/2/07	Sat 6/2/07
20	Sign the Contract	Sun 7/1/07	Sun 7/1/07
21	Commencement Date	Wed 8/1/07	Wed 8/1/07
22			
23	**Construction Period**	**Wed 8/1/07**	**Sat 2/2/08**
24	Commencement Date	Wed 8/1/07	Wed 8/1/07
25	Mobilization and Site Preparation	Wed 8/1/07	Thu 8/30/07
26	Preparation of Access Road	Wed 8/1/07	Sun 8/12/07
27	Key Excavation	Sat 9/1/07	Mon 12/31/07
28	*From Check Dam ST1 To Check Dam*	*Sat 9/1/07*	*Mon 12/31/07*
29	*From Check Dam HV To Check Dam I*	*Sat 9/1/07*	*Mon 12/31/07*
30	Embankment Works	**Sat 9/15/07**	**Tue 1/15/08**
31	*From Check Dam ST1 To Check Dam*	Sat 9/15/07	Tue 1/15/08
32	*From Check Dam HV To Check Dam I*	Sat 9/15/07	Tue 1/15/08
33	Instrumentation	Mon 10/1/07	Thu 1/31/08
34	*a- Runoff Recorder*	*Thu 11/1/07*	*Thu 1/31/08*
35	*b- Parshall Flume*	*Thu 11/1/07*	*Thu 1/31/08*
36	*c- Stand Pipe Piezometer*	*Mon 10/1/07*	*Thu 1/31/08*
37	Finishing Works	*Tue 1/1/08*	*Thu 1/31/08*
38	Handing Over	Sat 2/2/08	Sat 2/2/08
39			
40	**Defect Liability Period**	Sat 2/2/08	Wed 4/1/09

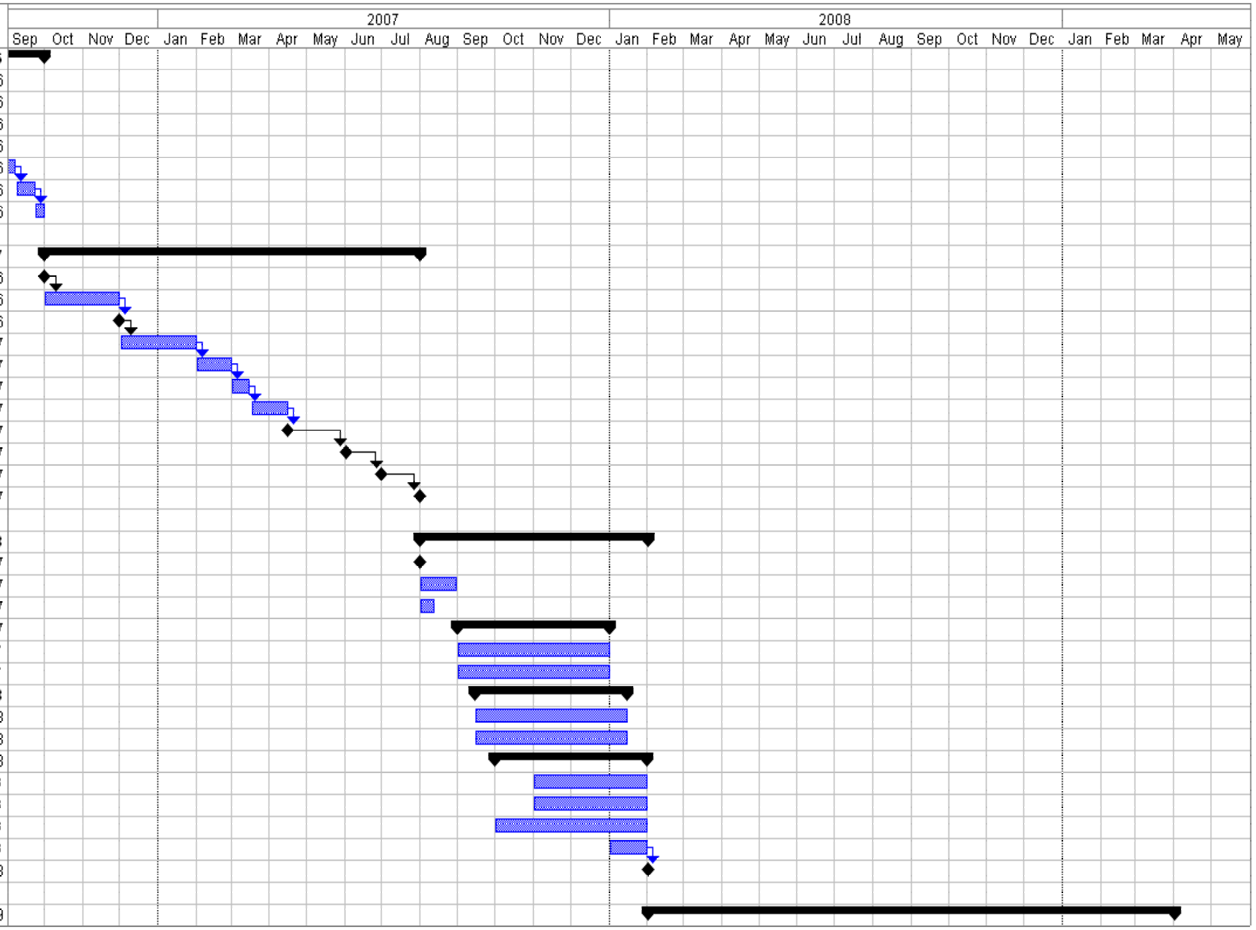

Figure 12.1 Procurement and Construction Schedule, Bahman Check Dams

Recommended Construction Period: 180 calendar days

Recommended Commencement of Works Date: August 1

SECTION THIRTEEN. TRAINING AND WORKSHOPS

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SECTION THIRTEEN. TRAINING AND WORKSHOPS

13.1 General

In accordance with the TOR and instructions provided by SBWMP in a 2 January 2006 letter, workshops for technical training, community and stakeholders were conducted within the duration of the detailed design project. Stanley Consultants conducted the training sessions at The Yemeni Businessmen's Club, a large, modern training conference room in Sana'a. The room was large enough for program evaluators to be present during the training, and for computers and electronic presentations to be utilized as part of the training courses.

The schedule of the training program was as follows:

Training Discipline	Number of People Attending Workshops	Dates	Lead Presenters
Dams and Hydrology	3 people	28th February and 1st March 2006	Dr. S D Kulkarni Dr Abdulsalam Kaid
Evaluation of Dams	4 people	4th and 5th March 2006	Dr. Sawsan Himmo
Environmental Impact Assessment	3 people	11th and 12th March 2006	Dr. Khaled Hariri
Community Workshop	12 Community Representatives	15th March2006	Dr Khaled Hariri Dr. Souad Othman Mohammad Noaman
Stakeholder Workshop	(5 people) 1-Ministry of Agriculture and Irrigation 1-Agriculture Office 1-Information Media 1-Ministry of Water and Environment 1-NWRA	16th March 2006	Dr. Khaled Hariri Dr. Souad Othman Mohammad Noaman

The training material for Dams and Hydrology, Evaluation of Dams and Environmental Impact Assessment were submitted to the PCU of SBWMP prior to the training sessions.

Community and stakeholder workshops have been held at Sana'a International Hotel and were attended by community, Ministry of Water and Environment representatives, and Arcadis. These workshops have been a success in communicating the project objectives and its benefits to the Sana'a Basin as whole.

13.2 Photographs

Dams and Hydrology

Evaluation of Dams

Environmental Impact Assessment

Community Workshop

Stakeholder Workshop

SECTION FOURTEEN: MONITORING PLAN FOR THE BAHMAN CHECK DAMS

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SECTION FOURTEEN: MONITORING PLAN FOR THE BAHMAN CHECK DAMS

14.1 Introduction

A good monitoring plan is an integral part of the long-term operation and maintenance of a dam. This dam monitoring plan is intended to identify deficiencies, unsafe conditions, and the maintenance required to assure the integrity of the structure to protect life, health, property, and the continued aquifer recharge functions the check dams provide. The Bahman Check Dams (27 Dams) Monitoring Plan includes provisions for the following:

- Routine and detailed inspections with annual reporting of assessment and recommended improvements or maintenance.
- Installation and reading requirements for instrumentation
- Management of instrumentation data

The Bahman Check Dam project serves as the pilot project in Yemen for this approach of artificial groundwater recharge. As such, it is imperative that comprehensive and accurate monitoring of the project performance be performed. The designers of future projects in Yemen will rely heavily upon the performance data and indicators that are collected from Bahman. This data will likely be utilized to optimize and refine their designs of check dam cascades in order to maximize the recharge of shallow aquifers.

14.2 Check Dam Inspections

Inspection of the Bahman Check Dams should be an ongoing process. Some aspects of the program are to be performed on a weekly basis (Routine Inspections) while other, more detailed inspections are to be performed on an annual basis (Detailed Annual Inspections).

14.2.1 Routine Inspection

The purpose of the routine inspections is to ensure routine surveillance of the check dams. The operating staff shall make frequent observations of the check dams and appurtenances and of the check dam's operation and maintenance. These observations shall occur at least once a week. Additional inspections shall occur immediately after large rainfall/runoff events. Staff shall identify and report abnormal conditions to supervisory personnel. All reported abnormalities are to be documented by the supervisor via report or memorandum. Items to be observed during routine inspections shall include the following:

A. Check Dams

- Erosion of abutments or area downstream of dam
- Loss or movement of rip-rap
- Seepage or sand "boils" downstream of dam toe

- Vortices upstream of dam
- Settlement of the crest
- Evidence of slope instability
- Unusual vegetation growth
- Excessive erosion or evidence of instability (slides or rock falls) of wadi slopes

B. Condition/security of piezometers

C. Parshall Flume

- Erosion upstream or downstream of flume
- Erosion of flume abutments
- Blockage of flume with debris or rubble
- Operation/security of runoff recorder
- Cracking, spalling or deterioration of concrete
- Settlement of flume aprons
- Rainfall recorder condition/security (Check Dam ST3)

14.2.2 Detailed Annual Inspection

The detailed annual inspection is performed as part of the operation and maintenance of the facility. This includes review and compilation of the information collected in the previous year's routine inspections. This also includes a review and formal recording of monitoring data and maintenance performed on the check dams during the previous year.

This detailed annual inspection will provide a thorough systematic evaluation of the check dams with the results presented as a formal report. A thorough and systematic field inspection of all of the check dams' piezometers and the Parshall Flume will be performed at this time by a qualified engineer that is familiar with the operation and maintenance of the dam. Only a professional engineer(s) experienced in the design, operation and maintenance of these dam structures and trained to recognize abnormal conditions shall be used to perform this inspection. This person may be a member of the GDI staff or an Independent Consultant.

The annual inspection will include the items outlined above.

14.2.3 Inspection Reporting

The results of the detailed check dam inspection shall be documented in a report that contains identified problem areas, deficiencies of check dam or flume components, condition of piezometers, recommended remedial actions for problem areas, a priority list and schedule for remediation of problem areas, and recommendations for additional inspections or investigations if necessary. Problem areas shall be documented with pertinent photographs properly labeled for easy reference. The report shall contain results of all testing and surveying performed as part of the inspection.

Timely repairs are imperative once problem areas have been identified. Prompt scheduling of the repair of problem areas is an important component of a good rehabilitation and maintenance program. The Inspection Report shall contain a "checklist" of recommended maintenance and repairs. Repair priorities shall be identified on the checklist and shall be based on identified indicators of potential problems, signs of warning and concern, and or signs of disrepair. The checklist shall identify action items in need of repair, monitoring, or further investigation. A system to address the condition of dam and flume components can be set up to follow these codes:

NE – No Evidence of Deficiency
MM – Minor Maintenance Identified
IM – Immediate Maintenance
EC – Emergency Condition
NI- Not Inspected
GC – Good Condition
RO – Regular Observation

The Inspection Report shall include an estimate of the cost of recommended repairs and maintenance as well as an opinion of remaining service life of the structural components of the dam and flume based on implementation of the recommended repairs and maintenance.

14.3 Instrumentation and Reading / Monitoring Requirements

14.3.1 Instrumentation

The following instrumentation will be installed at the Bahman Check Dams:

- One (1) Piezometer at each check dam
- Runoff Recorder at Parshall Flume
- Rainfall Gauge near Check Dam ST3

NWRA may wish to install a climateological station, or other measuring equipment, within the Bahman Check Dam site. The installation, monitoring, and data collection to be provided by this equipment is outside of the scope of this report.

14.3.2 Reading / Monitoring Requirements

The collection of complete and accurate data from the Bahman Check Dam Project instrumentation is imperative to the evaluation of the project's performance as a shallow aquifer recharge facility. In Addition, the data collected will be used to optimize future designs in order to maximize recharge of other aquifers. Because of this, the reading /

monitoring of the check dam instrumentation should be performed by trained GDI personnel or another qualified, professional contractor. Failure to collect comprehensive and accurate data for this pilot project will represent a lost opportunity to optimize future artificial recharge designs.

Instrumentation	Interval
Piezometers	Daily when water is impounded
	Weekly for one month after impoundment is dry
	Monthly during dry periods
Runoff Recorder	Weekly to change recorder chart
Rain Gauge	Weekly to change recorder chart

The collected data will be useful in establishing a water balance model, integrating rainfall, flood flow and recharge of the alluvial aquifer. The rainfall and runoff data can be integrated to develop a rainfall/runoff relationship. The runoff and piezometer data can be used to develop a recharge model in order to calculate infiltration volumes. These two models can then be integrated to establish the water balance of the Bahman Catchment.

14.3.3 Management of Instrumentation Data

All collected data will be compiled and submitted to supervisory personnel on a weekly basis. Any abnormalities observed during data collection should be reported to supervisory personnel immediately. In addition, all collected data will be compiled and included in the Annual Detailed Inspection Report.

A data base would be useful for managing the recorded data. A data base is a useful tool for organizing and retrieving records in an easy and efficient manner. This will assist in producing weekly, monthly and annual reports.

14.4 Importance of Bahman as a Pilot Program Site for Check Dams

The Bahman Check Dam project may serve as the “pilot” project for future artificial groundwater recharge projects in Yemen. As such, it is **imperative** that consistent, comprehensive and accurate monitoring of the check dams' performance be made a priority. The data collected from the Bahman project will be used by future designers and agency officials top optimize and define the design of future groundwater recharge projects.

In order to obtain maximum advantage of the experience of the Bahman Check Dam project, recommendations for the maintenance, instrumentation, data collection and reduction for the project are provided. Also provided is a discussion of responsibility for these tasks. Without appropriate assignments and responsibility for each task, success in regular monitoring and recording of project data will be difficult to achieve.

14.4.1 Maintenance of Instrumentation

If the project facilities and associated instrumentation are not properly maintained, the benefits of the project will be severely diminished. Following is a list of items that must be maintained in a clean, fully functional condition:

Siltation upstream of each check dam must be removed on a regular basis. It is recommended that silt be removed following the completion of each rainy season. This desiltation could be accomplished by local farmers or other individuals who might wish to utilize this silt for agricultural purposes.

The Parshall Flume must be structurally maintained and free of debris. Flow through the flume cannot be obstructed or reduced by the presence of debris and trash.. Recording paper must always be available at this site. Piezometers shall be maintained in a clean, open, fully functional and protected condition.

Access to the dam sites must be maintained to allow easy access for personnel responsible for monitoring the instruments.

14.4.2 Instrumentation Data Collection

Without consistent, reliable, and accurate data collection, the potential value of this pilot project will not be realized. Section 14.3.2 outlines the **minimum** requirements for data collection for the project instrumentation.

14.4.3 Management/Processing of Instrumentation Data

The value of data collected in of no more value than the quality of the management and processing of this data. As data is collected from the field, it must be reviewed for completeness, accuracy, and reasonableness by a qualified individual, and the information must then be must then expeditiously and accurately entered into a database. The hard copies of this field data shall be properly and safely filed for future use.

The databases shall be processed and reviewed on a regular basis (at least twice per month) by a qualified professional. This processing and review will include reviews for reasonableness of results, trends, and anomalies in data. The need to modify any received data collection frequency or calibrate / inspect field instrumentation will be considered at this time.

14.4.4 Responsibility

All of the above discussion is contingent upon qualified, responsible parties being assigned to complete these respective tasks. Several options exist for the various task responsibilities. Suggestions for these tasks are as follows:

14.4.5 Maintenance Responsibility

Maintenance is responsibility can be assigned to a local contractor, or it may remain with the local water agency / WUA. It is recommended that professional oversight and quality control is provided by GDI or another professional engineering consultant experienced in dams and instrumentation. Professional oversight and review should consist of regular communication with a maintenance contractor through GDI; regular inspection of sites (no less than one time per month); and inspection/quality assurance of any repair work performed on the project facilities . Documentation and reporting of all repair and maintenance work should be submitted to GDI at least twice each year.

14.4.6 Data Collection

Data collection should be performed by GDI or by a qualified, professional consultant. All data collection, whether by GDI or another party, shall be performed by trained, skilled individuals under the supervision of a professional engineer. This engineer should be experienced in dam design, evaluation, construction and instrumentation. If data collection tasks are contracted to a professional engineering consultant, a GDI project manager should be assigned to this activity. Continuity of oversight is critical to the long term success of the data collection effort. Open and frequent communication between GDI project management and the professional consultant must be maintained.

14.4.7 Management / Processing of Instrumentation Data

As with the data collection task, this task may be performed by GDI or a professional engineering consultant. As mentioned above in data collection, the same requirements for qualifications, supervision and communications will apply to this project requirement.

14.4.8 Overall Project Management

Regardless of the outcome of the decision to perform monitoring tasks internally to GDI, or to hire a consultant to provide this work, GDI should assign a senior project manager to the Bahman O&M effort. This individual will be responsible for the entire Maintenance and Monitoring Program.

A GDI senior Project Manager should be responsible for the responsibility, quality, continuity and success of this important "pilot" project. Any changes in management should be accompanied by proper training and orientation to assure continuity is maintained.

Proper monitoring, maintenance, and evaluation of the performance of the Bahman Check Dams will cost money. If possible, the costs of these efforts should be shared between GDI and the local WUA and community. The community members could contribute their share of O&M activities through in-kind labor if the community is unable or unwilling to provide money for the maintenance of these dams. The instrumentation should remain under the control of GDI, consultants hired by GDI, or other professional individuals who are able to properly maintain and evaluate the performance of the instrumentation.