ODU BULLETIN

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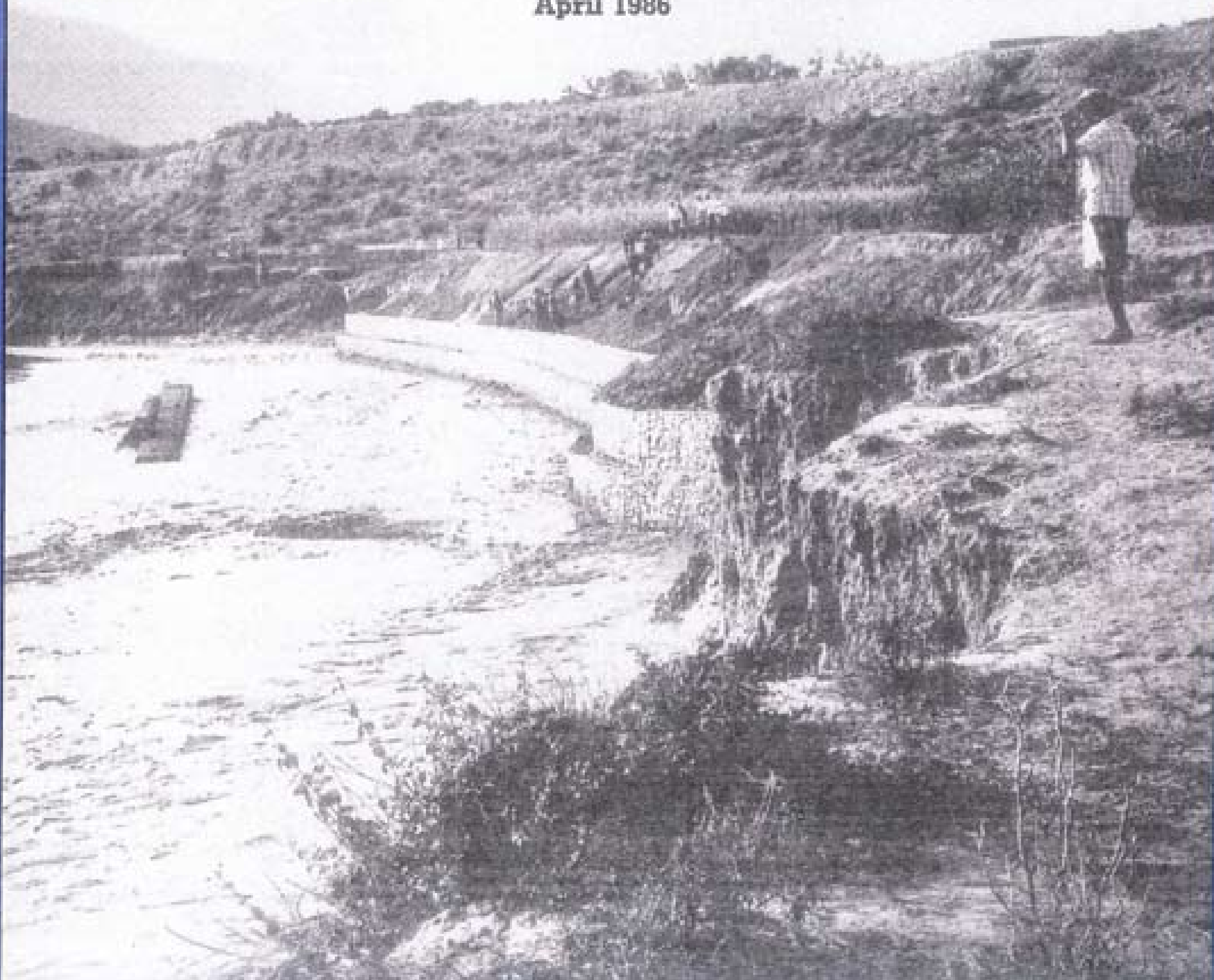
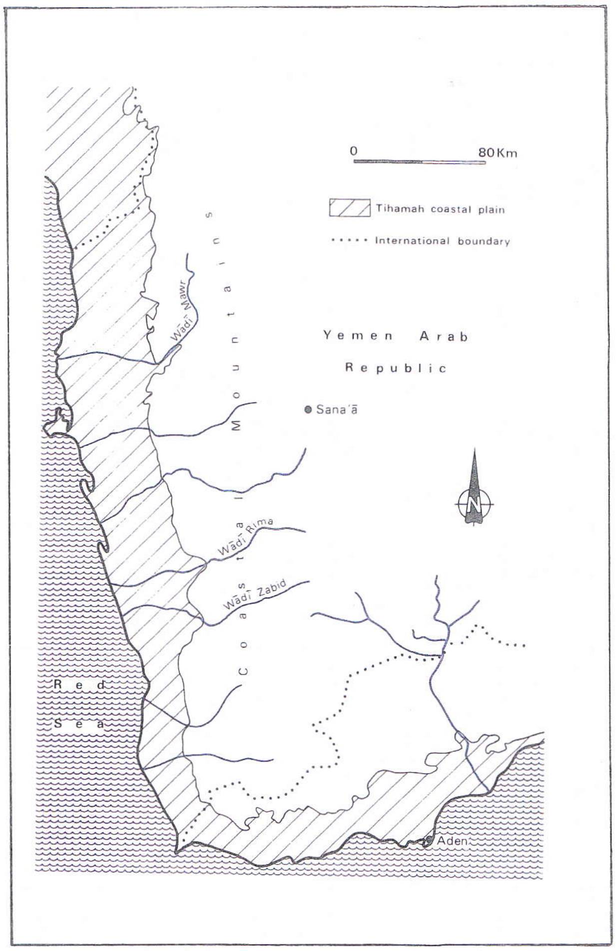


Hydraulics Research
Wallingford

Spate irrigation in the Yemen Arab Republic

by Philip Lawrence

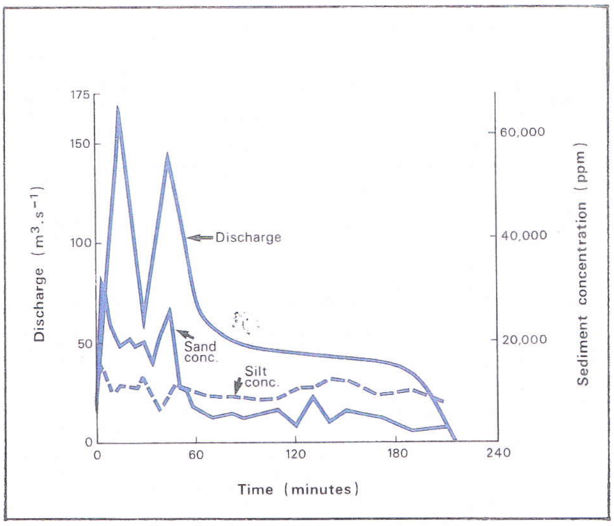
The traditional spate irrigation systems of the Tihama coastal plain in the Yemen Arab Republic are undergoing radical change as they are developed and improved. The ODU has tested diversion structures utilising a unique spate flow test facility. Field measurements in two wadis have also been undertaken. In this article the problems of diverting water from steep rivers subject to flash floods are outlined, and some of the engineering solutions that have been adopted are described.



Yemen Arab Rebublic

Wadi characteristics

The Tihama plain has a generally arid and tropical climate with annual potential evaporation rates of around 2500 mm. The annual rainfall of 500 to 600 mm falls in tropical storms over the mountainous catchments to produce short, often multi-peaked, floods. Peak discharges can rise to more than 2000 m^3s^{-1}. Flood hydrographs, such as the typical one shown, exhibit a very short rising limb and a 4 to 6 hour recession. Wadi flows are seasonal with about 80% of the total annual discharge occurring between April and November. Base flows in the dry season are often less than 1 m^3s^{-1}.



Although most of the runoff occurs during the flood season, a surprisingly small percentage of the total annual discharge occurs at very high flow rates, as shown in the data from the Wadi Rima.

Flow Range m^3s^{-1}	% of Average Annual Discharge in Flow Range
Less than 2.0	53
2.0 to 5.0	21
5.0 to 10.0	11
10.0 to 20.0	7
20.0 to 50.0	4
50.0 to 100.0	2
100.0 to 500.0	1.5
Larger than 500	1.5

Clearly in this case a high diversion efficiency can be achieved if all the wadi flows, up to say 20 m^3s^{-1}, can be abstracted. A similar distribution has been found in the other Tihama wadis.

Wadi bed widths vary from 100 to 300 m at potential diversion sites where the wadis flow from the mountains onto the Tihama. Gradients are typically steep, 0.4 to 1% and when not in flood the wadi bed is occupied by small, meandering, often braided, low flow channels. Bed material is poorly sorted ranging in size from silt to boulders. During floods very large quantities of sediment in the sand size range are transported. Until recently very little reliable sediment transport data was available, particularly for high flows.

The ODU, in collaboration with the Tihama Development Authority, (TDA), have successfully measured the sediment concentrations during floods in Wadi Zabid utilising specially developed automatic pump sampling equipment, (similar to that described by Amphlett in the January 1986 issue of the ODU Bulletin). This has enabled sediment concentrations in the sand range to be measured during flood peaks and at very high wadi discharges when conventional bottle sampling methods cannot be used. The measurements show that variation of the sand size fractions during a flood are sensibly related to discharge. Field measurements, like these, are important as conventional sediment transport equations cannot be used to predict sediment concentrations which can rise to more than 10% by weight at high wadi discharge.

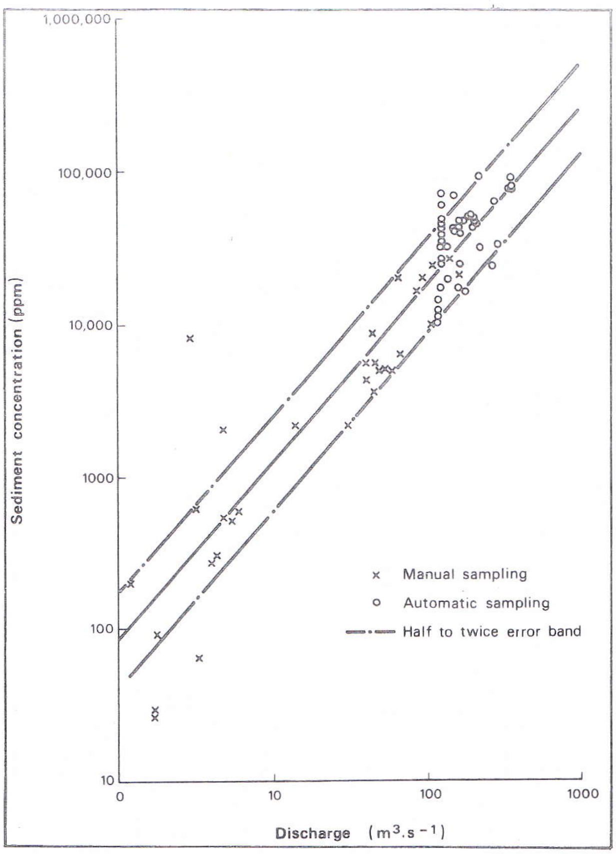
These concentrations are far in excess of the carrying capacity for conventionally-designed canal systems, and highlight the requirement for sediment exclusion or extraction if the high costs of frequent canal de-silting are to be avoided.

The positions of the low flow channels within the wadi bed are often unstable and large, lateral, shifts are observed following floods. As most of the water resource is available for diversion at relatively low discharges either the intake structures must be built to cope with these changes or the low flow channel position must be stabilised at the canal offtake.

Criteria for a wadi diversion structure

An ideal wadi diversion structure would exhibit the following features:

- All wadi flows up to a certain discharge should be diverted. The cut-off point will depend on the flow statistics for a particular wadi and on economic factors.
- The position of the low flow channels must be stabilised at the off-take.
- Concentrations of sand sized sediments entering canals should be minimized. An alternative would be to design canal systems to transport these high concentrations of bed material through the canal systems and on to the fields.
- Gate operations should be quick and as simple as possible, to cope with rapid variations of flow.
- Permanent structures must be capable of withstanding the very high flood discharges generated by extreme rainfall events.



Wadi Zabid - sediment concentration

Traditional systems

Present irrigation development in the Tihama is taking place against the background of existing, well-established, spate irrigation systems. In some wadis a high proportion of the available water was, and still is, being diverted and used relatively effectively. Irrigated areas are already sculptured with patterns of bunded fields set at different levels and supplied from canals. Water distribution is controlled through a system of water rights, based on the Islamic principle that upstream users take priority, but usually including a form of time-sharing which gives all irrigators some probability of receiving water.

Traditional offtakes consist of low stone and brushwood deflectors which are built out into the wadi bed to intercept the low flow channels and divert water into un-gated and un-lined canals. In the headreach, canals follow the local land gradients and are very steep in comparison with conventionally designed canals.

The occurrence and magnitude of floods are not predictable so farmers attempt to divert the maximum quantity of water during the very short duration of the floods. Bunds are built across canals and all of the canal discharge is then passed from field to field until water has reached all the fields under command. The canal bund is then breached and the water is passed on to the next group of irrigators.

This traditional water diversion system meets many of the criteria listed earlier. The predominance of low flows is such that a high diversion efficiency can be achieved with a system of 20 or more traditional offtakes even though upstream diversions are washed out in floods. The deflectors can be rapidly adapted to cope with movements of the low flow channel and with rising bed levels in the wadi channel. The steep canals ensure that sedimentation does not occur in the canal head reaches.

However, the system is very labour-intensive, canals are often damaged by flood flows and deflectors are constantly having to be rebuilt following flood damage. In recent years the large scale emigration of male labour from the area to neighbouring oil states has made the traditional systems increasingly difficult to operate. There is also great uncertainty in the timing and magnitude of the water supplies that will be received by irrigators who do not have access to base flows.

Recent developments

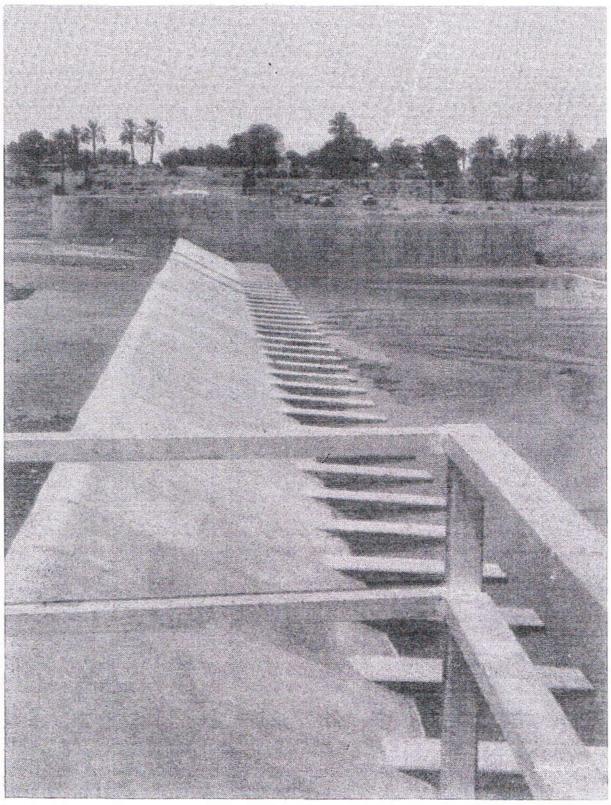
One approach to irrigation development in the Tihama would be to improve the existing traditional systems. The use of gabions could enable farmers to build stronger canal heads and deflectors, whilst some linking of traditional canals would allow base flows to be passed from the point of abstraction at the head of wadis to downstream users, thus improving the reliability of irrigation supplies. The ODU, in collaboration with the TDA, have assessed the durability of gabion structures in the Wadi Rima, and have also carried out a series of model tests utilising the HR spate flow facility to determine the best configuration for a simple, low cost diversion structure constructed from gabions. However, this approach has not found favour with either the government of the Yemen Arab Republic or funding agencies. The following paragraphs describe some features of the offtake structures that have been selected for the first three wadis to be developed.

Wadi Zabid

Wadi Zabid, containing one of the oldest traditional irrigation systems, was the first to be developed with new water diversion structures. Five conventionally designed diversion weirs, four with canal offtakes on both banks, were commissioned between 1980 and 1981. The structures replaced some 16 existing traditional offtakes and new headreach sections of canal were constructed to link the new structures with the existing traditional canal network. The total capacity of the new canal system is 238.5 m^3s^{-1}.

The experience gained from operating the Wadi Zabid system and the results of performance monitoring by HR have shown that operation of a large number of conventionally designed offtakes is difficult and some aspects of performance have been poor.

Floods usually occur at night when the central gate operation staff are off duty making operation of the large number of offtakes and sluiceways difficult. Division of low flows between offtakes on both banks has been hampered by the rapid rise in bed levels upstream from the structure. Bed levels rose to weir crest level very quickly following construction and eliminated the possibility of utilising the ponding effect provided by the weirs. Sediment deposits in the canals have increased canal bed slopes by a factor of two or three over the design slopes, and sediment deposition in the headreaches has resulted in a large reduction in canal capacities. Canal flow measurements by the ODU and TDA have shown that as much as 70% of the water, that could have been abstracted in floods, passes over the weir.



Wadi Zabid structure 1 weir

Wadi Rima

Following the experience gained from the Wadi Zabid, the design of the Wadi Rima system, which was commissioned in 1983/84, followed a radically different concept. Only one offtake has been constructed at the head of the wadi and water is passed to canals by a long supply canal running parallel to the wadi bed. An under-wadi siphon has been constructed to pass irrigation supplies to a similar canal running parallel to the wadi on the other bank. The main canal discharge has been restricted to 15 m^3s^{-1}, selected on the basis of the flow statistics given in the table.

The weir contains a sloping crest to stabilise the low flood channel at the offtake side of the structure. Under-sluice tunnels were provided at the offtake to prevent large bed material entering the canal during floods. A small settling basin was incorporated in the canal head reach to trap coarser sediments.

This system is reported to be operating satisfactorily although problems have occurred with boulders and trash blocking the under-sluice channels. A number of other trash-related problems have been reported.

Wadi Mawr

A new diversion structure is under construction in the Wadi Mawr. The designers of the structure followed similar concepts adopted in the design of the Wadi Rima offtake, ie a single offtake containing a sloping weir diverting water to supply canals parallel to the wadi. For the first time in a Tihama wadi a major sediment control structure has been incorporated. Two sluiced settling basins are to be used to control the entry of sediment in the sand size range to the main canal. The basins will be flushed with the excess water available for short periods during flood peaks, with back-up provision for manual desilting.

The design of new irrigation diversion structures for the Tihama have evolved as experience has been gained, and the latest structures incorporate most of the features that are necessary if reliable performance is to be achieved. However, diverting water and controlling sediment in spate wadis will continue to be a challenging technical task. Quantitative performance monitoring will continue to have a large role to play, both in determining the best operating strategy for existing structures and in providing information upon which future designs can be based.

Silted canal - Headreach, Wadi Zabid system

Spate flow facility

The use of ephemeral rivers for irrigation is increasing. The two articles in this issue of the ODU Bulletin describe some of the developments to utilise this valuable water resource. To assist design engineers in this task a new model facility has been developed, at Hydraulics Research, to study the performance of irrigation offtake structures in steep rivers subject to flash floods.

The facility was developed using funds made available by the British Overseas Development Administration and has been used successfully to examine structures proposed for three wadis in the Yemen Arab Republic.

The problem. Flash floods are often associated with steep rivers that can transport sediment concentrations rising to more than 10% by weight. During these floods river flows can increase from a base flow of 1 m^3s^{-1} to over 1000 m^3s^{-1} in under 30 minutes, followed by a flood recession with a duration of 4 to 10 hours.

Though low flows often provide the bulk of the usable water resource, flash floods can re-work the bed of the river and alter the position of the low flow channel. High sediment concentrations during peak flows and flood recessions can lead to accretion in offtake canals. Maintaining heavily accreted offtake canals is expensive.

The spate flow facility provides the essential features for modelling structures in rivers prone to flash floods. It can:

- simulate floods with rapid changes in flow;
- feed sediments at variable rates;
- use wet sediments to allow model materials to be re-used without drying;
- accurately measure model parameters such as bed levels, discharges, sediment concentrations; and
- allow model runs under automatic control to be repeated with confidence.

The model basin has been built with the following features:

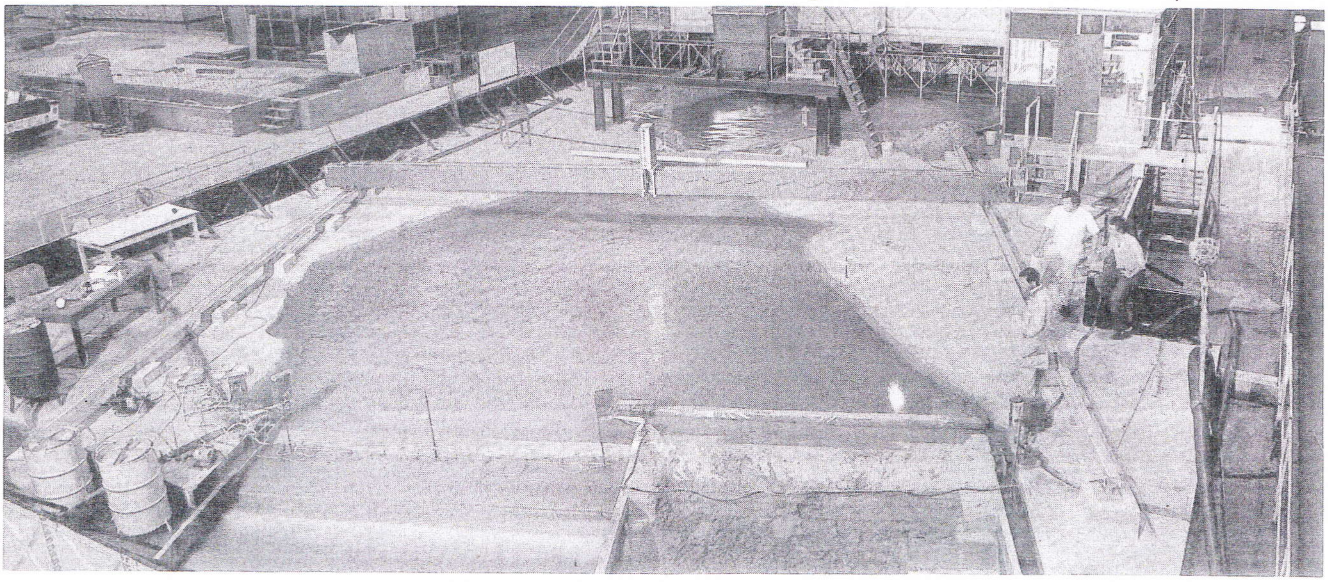
- clear model area—up to 570 m^2;
- control system capable of generating, most natural floods and corresponding sediment hydrographs;
- bed profiler, data logger and XY plotter for quick bed surveys;
- sediment sampling systems to quantify rates of sediment flux; and
- automatic water level sensors connected to the data logging unit.

The flood flow generator provides:

- a discharge range of 0 to 300 ls^{-1};
- repeatability at peak discharge of about 1% and repeatability at 10% of peak discharge of about 3%; and
- a discharge cycle of zero flow to peak flow in 3 minutes.

The automatic sediment feeder

works on the principle of the Archimedian screw, where sediment supply is modified by varying the rotational speed of the screw. This novel design permits injection of saturated non-cohesive material at controlled rates ranging from 0.003 kg s^{-1} to 15 kg s^{-1}. The accuracy of sediment delivery is typically 10% over a wide range of injection rates. The feeder can be pre-programmed to work in conjunction with or independently of the flood discharge.



Spate flow facility