The Management of Siltation at Hillsborough Dam, Tobago

D A BRUGGEMANN AND J D GOSDEN, Jacobs Babtie (formerly KBR)

SYNOPSIS

Hillsborough Dam is situated on the Hillsborough East River, 4 km north of the village of Mount St George on the island of Tobago and is owned and operated by Trinidad and Tobago Water and Sewerage Authority (WASA). The dam, commissioned in 1952, forms one of the main sources of water supply for the island of Tobago.

WASA have been concerned for a number of years that the volume of Hillsborough Dam was decreasing due to the deposition of sediment in the reservoir. In 2004 Inter-American Bank funding was obtained by the Government of Trinidad and Tobago to let a contract for the feasibility study and detailed design for desilting and rehabilitation works at Hillsborough Dam, Tobago. The project was carried out between January and August 2005.

The paper describes the investigations that were carried out to determine the extent of siltation, discusses the causes of siltation, describes methods proposed for desilting the reservoir, outlines the environmental legislation and discusses issues related to the disposal of silt. The paper concludes with proposed methods for future reservoir and catchment management.

INTRODUCTION

The island of Tobago is approximately 42km long and 12km wide at its greatest width. The island lies 32km north-east of the island of Trinidad and 120km north-east of Venezuela in South America.

Hillsborough Dam is situated on the Hillsborough East River, 4 km north of the village of Mount St George on the island of Tobago and is owned and operated by Trinidad and Tobago Water and Sewerage Authority (WASA). The dam forms one of the main sources of water supply for the island of Tobago. It is believed that first excavations began in 1944 and the dam was

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officially commissioned in 1952. The dam is about 18m high and comprises an earthfill embankment with a concrete core wall which was keyed into the foundations. The draw-works comprise a 450mm (18 inch) diameter draw-off pipe positioned on the upstream face of the dam, with draw-off valves at three elevations. A masonry cascade spillway (Figure 1) with a crest length of 30m is provided on the right abutment. The design capacity at maximum retention level is $1.03Mm^3$ (about 227 million gallons).

Figure 1 – Masonry spillway in need of rehabilitation

The catchment is about 5km long with an area of $5.2km^2$. The valley side slopes are generally steep and the average gradient of the river is about 12%. The average rainfall at the dam is just over 2,200mm per annum.

Soil erosion was known to be a problem in some parts of Tobago as a result of deforestation and poor agricultural practices. Initially, it was not believed to be a significant problem in the Hillsborough catchment because most of the catchment was covered by rainforest which has had forest reserve status for over 100 years with no development permitted since the commissioning of the dam. Nevertheless WASA was concerned that storage at Hillsborough Dam was being lost as the result of siltation of the reservoir.

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GEOLOGY OF THE STUDY AREA

The island of Tobago is composed mainly of Mesozoic igneous and metamorphic rocks which evolved in an oceanic island arc. Hillsborough Dam is located in the Bacolet Formation which is principally composed of pyroclastic deposits comprising tuffs and agglomerates of labradorite and andesite with intercalated lava flows of similar composition. The catchment area is underlain by rocks of the mid-cretaceous plutonic suite comprising diorite-gabbro over the southern half and ultramafic rocks over most of the northern half. The geology changes from the Bacolet Formation to diorite-gabbro about halfway up the reservoir.

Brown et al (1965) noted that the soils (sandy loams) derived over the deeply weathered friable diorite erode readily leaving a thin cover of soil, or in some cases bedrock.

EXTENT OF SILTATION

The extent of siltation was difficult to determine because the datum used to derive the original Elevation – Volume curve was unknown, there was little published information on soil erosion studies for Tobago, bathymetric survey was hampered by dense vegetation (see Figure 2) which prevented access to the edge of the lake and the most recent aerial photography was more than 10 years old.

The first report which acknowledged that siltation might be taking place was prepared in 1996 (Howard Humphreys, 1996) for an inspection carried out following the principles of Section 10 of the UK's Reservoirs Act, 1975. The original reservoir Elevation – Volume curve was compared with a curve prepared from a hydrographic survey carried out in 1986. This suggested that there had been a significant reduction in the volume of water stored in the reservoir since commissioning in 1952. However, in 1996 it was recognised that the elevation datum used for each curve was different and therefore no firm conclusions were drawn at that time.

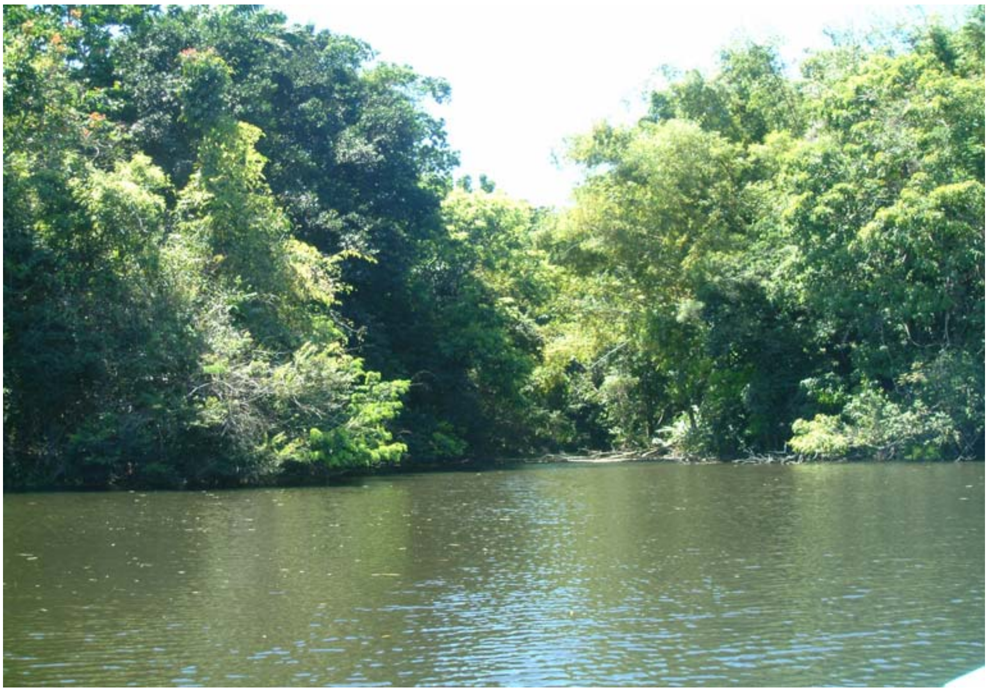

Figure2 – Vie w of lake shore showing dense vegetation

Investigations

In order overcome the difficulties identified above it was necessary to estimate the extent of siltation using several methods and these included the following:

- Desk study to evaluate existing data including published information on soil erosion in Trinidad and Tobago
- Bathymetric survey of the reservoir using the Medusa system
- Silt depth probing
- Reconnaissance of the lake and catchment
- Examination of turbidity measurements at the treatment plant

Information examined during the desk study included the original Elevation-Volume curve and a hydrographic survey carried out in 1986 which formed the basis of the Elevation – Volume curve included in the 1996 Inspection Report. These curves suggested that about 180,000m^3 of reservoir capacity had been lost to siltation over 36 years.

Little information has been published on soil erosion in Trinidad and Tobago. Ahmad and Breckner (1974) investigated the rate of erosion of three soils in Tobago without any vegetation cover i.e. bare soil, thus the data was not directly applicable to the forested catchment of Hillsborough

Dam. A search on the internet, (TriniNetwork.com, 2000)) provided information on soil erosion from a study carried out in the Northern Range in Trinidad. There was no indication of the source study, but the information indicates erosion yields between 50 and 5,000 tonnes/km^2/year for forested and bare soil respectively.

The data provided by Ahmad and Breckner suggested that the sediment yields for bare soils in Tobago could be twice those for the Northern Range in Trinidad. The sediment yield was estimated on the basis of a weighted average assuming 90% of the catchment was forested and 10% was bare soil on the basis of the Northern Range data for forest adjusted for Tobago soils. Using a silt density of 1.3tonnes/m^3, the weighted average silt volume was estimated to lie between 236,000m^3 and 307,000m^3 over 53 years.

A diving survey carried out in 2002 indicated silt depths of up to 2.4m (8 feet) thick. This survey estimated that there was about 85,000m^3 of readily dredgible silt. This estimate was considerably less than the volume suggested by the shift in the Elevation – Storage curves but was based on relatively few silt depth measurements.

A bathymetric survey was carried out in February 2005 using a Global Positioning System in conjunction with the Medusa system. This system comprises a probe dragged over the floor of the reservoir gathering information on water pressure, background gamma radiation and reservoir bed roughness which are translated into water depth, chemical composition and physical characteristics. Fifteen sediment samples were taken for chemical and physical testing to calibrate the Medusa readings.

The results of the bathymetric survey were used to build a digital terrain model (DTM) of the reservoir floor and derive an up to date Elevation – Volume curve. The Elevation – Volume curves determined over the life of the dam are shown in Figure 3 below which indicates an ongoing loss of storage volume.

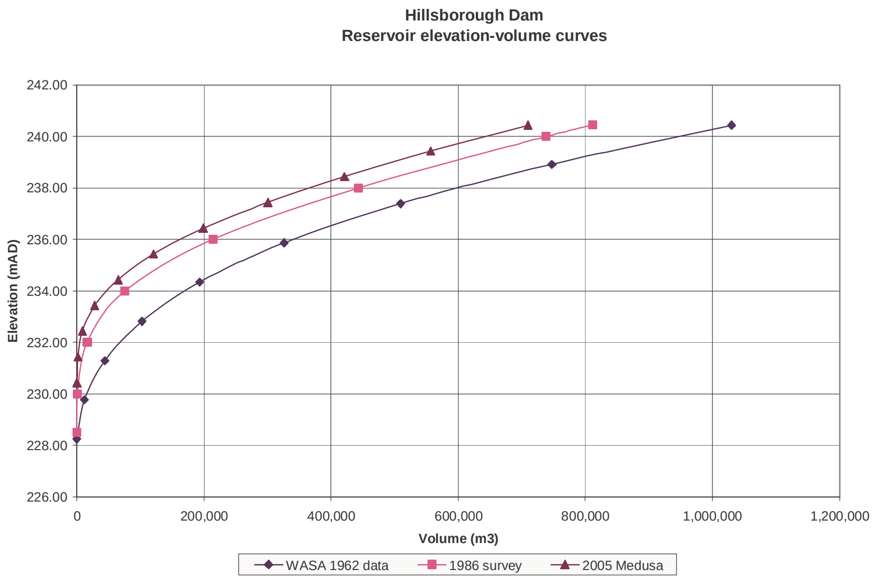

Figure 3 – Elevation – Volume Curves

The extent of siltation was also investigated by probing the depth of silt using a 19mm diameter pipe with a 100mm diameter foot plate. The pipe with foot plate attached was lowered from the boat until it rested on the surface of the silt and the depth of the water was recorded. The foot plate was then removed and the pipe lowered to the surface of the silt and then pushed into the silt until refusal. It was estimated that the pipe refused when the consistency of the silt was about 130kPa i.e. in the stiff range (BS5930). Estimates of the volume silt in the reservoir area up to the refusal depth were between 100,000m^3 and 150,000m^3.

The head of the reservoir where the Hillsborough East River discharges into the lake was accessed from the reservoir side. This visit revealed that the river outlet area was completely silted up. Silting up of the tributary river outlets was also observed. The silting up of the reservoir inlets also has an impact on bathymetric surveys as the reservoir surface area at top water level has decreased over time.

This behaviour is typical of reservoir siltation where silt deposition starts at the upstream end of the reservoir and migrates towards the dam. Additionally throughout the reservoir the extent of islands shown on the old mapping had also increased substantially through deposition of sediment in shallow water. The volume of silt deposited in these areas was estimated at about 60,000m^3. A typical silted up inlet is shown in Figure 4

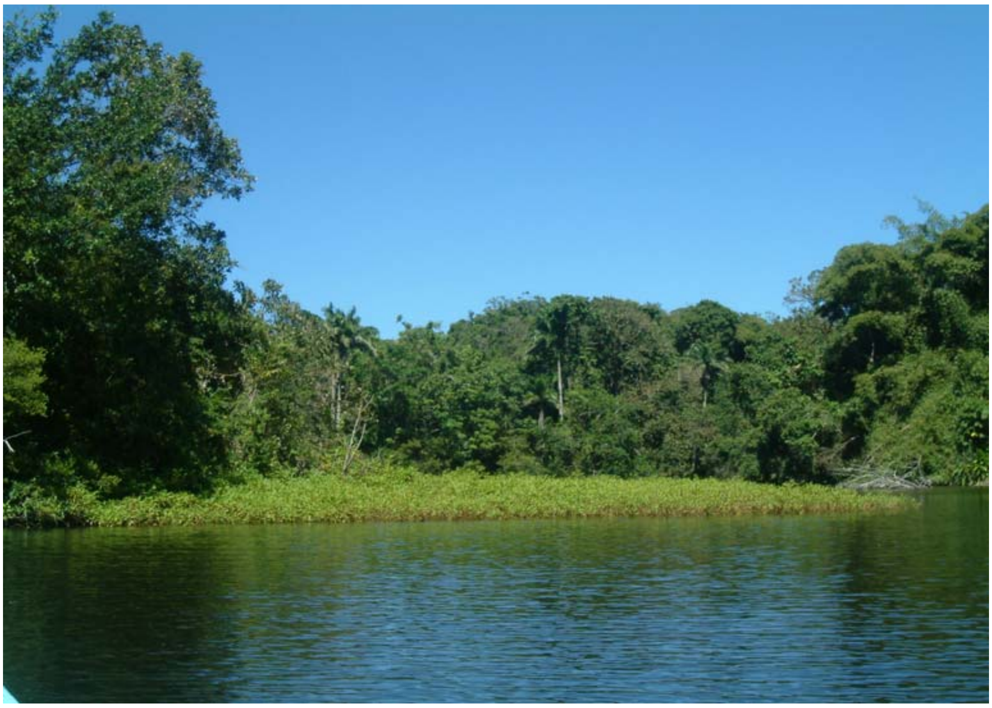

Figure 4 – Typical silted up river inlet

In order to determine a reasonable estimate of the volume of silt to be dredged, the sediment yield was calculated for a range of methods as shown in the Table below.

Table 1 – Sediment Yield Estimates

Source	Volume (m^3)	Sediment Yield (tonne/km^2/year)
Silt volume, catchment yield estimate (published data)	115,000-220,000	550-1,050
Comparison of 1962 and 1986 Elevation – Volume Curves	218,000	1,600
Comparison 1962 and 2005 Elevation – Volume Curves	320,000	1,500
Silt volume, 2002 estimate	>85,000	>400
Silt volume (readily dredgible), 2005 estimate (current study)	160,000 – 210,000	750 – 1,000

Examination of the above Table shows that the comparison of the Elevation – Volume curves give relatively consistent sediment yields of 1,500 t/km^2/yr and 1,600 t/km^2/yr. These estimates are also of the same order as that estimated from the published data on soil erosion rates and the readily dredgible volume from the current investigation. On this basis the volume of silt deposited in the lake was estimated at 320,000m^3 from the Elevation – Volume curves. The silt depth probing calculations estimated a volume of between 160,000m^3 and 210,000m^3 of silt. The probing penetrated soft to stiff deposited silt and therefore it was postulated that there was about 110,000m^3 of very stiff to hard silt that was not penetrated by the probe. The presence of compact layer of sediment is credible as the reservoir is drawn down to minimum levels frequently and thus cyclical increased effective stresses in the silt deposits over 50 years could create a highly consolidated and thus compact layer of silt.

CAUSES OF SILTATION

A reconnaissance of the lake and catchment was carried out by boat and on foot. The reconnaissance revealed that the catchment was not completely undisturbed and the remnants of an old public road (Mt. St. George to Castara) were still present as well other tracks understood to have been constructed when limited timber extraction was permitted for a short period. Maps showed that the old public road ran along the whole length of the western edge of the catchment boundary.

Erosion features were observed along the route of the old public road and on some of the secondary tracks. Where the track has been cut into the side of the valley, numerous localised slope failures were noted in the face created by the cut. These slips were of significant size, often up to 4m long by 3m high. It was also noted that vegetation did not re-establish itself in the slipped material or on the exposed face and thus slope failures provide a constant source of silt. Other features such as localised erosion gullies were also observed in some place along the edge of the tracks.

The reconnaissance thus revealed significant catchment disturbance and there was anecdotal evidence that illegal logging continues to be carried out thus causing further degradation of the catchment.

Morris and Fan (1997) mention that dramatic variations in sediment yield may occur, even in small catchments, when subject to disturbance. They present data for a small (4ha) catchment which showed that watershed disturbance by logging activities can cause the ratio of the disturbed to the undisturbed catchment yield to increase from 2 for minimal disturbance to 550 for the mass erosion of haul roads. Therefore, the evidence of past logging activities and the old public road in the catchment of Hillsborough Dam substantiates estimated sediment yields for Hillsborough Dam well in excess of those given for a forested catchment in the Northern Range of Trinidad.

PROPOSED METHOD OF DESILTING

Design Criteria and Operational Constraints

In determining the most appropriate dredging techniques, the duration of the works and particular requirements of the works the following design criteria and operational constraints were applied:

- The reservoir is to remain at its normal operational levels, i.e. the level cannot be reduced to facilitate the dredging works;
- Excessive suspended solid levels are to be avoided in the vicinity of the intakes;
- Dredging works are to be undertaken during the rainy season over a maximum period of 6 months (24 weeks);
- Enabling works can take place during the dry season;
- The upper reaches of the reservoir where the sediments are at or above the Top Water Level (TWL) will need to dredged when the reservoir is full or within 200mm of TWL;
- Dredging level to be to a "clean" dredge to the original reservoir bed, a maximum depth of about 12m from top water level (240.44m AOD) to include for dredging below the invert of the bottom intake;
- The reservoir is to remain operational at all times during the dredging works;
- The gross volume to be dredged is assumed to be 320,000m^3 giving a net volume of 256,000m^3 allowing for 20% being un-recoverable;
- Dredging tolerance to be +0mm to –500mm

Dredging Methods

The relative merits of various inland dredging methods were examined in the context of Hillsborough Dam and a preferred method was then recommended. The methods examined included the following:

- Backhoe from pontoons
- Dragline
- Cutter suction
- Excavators and bulldozers in a dewatered reservoir

Backhoe dredging mounted on a pontoon was recommended as the most appropriate method as it has the following advantages:

IMPROVEMENTS IN RESERVOIRS

- Backhoes are readily transportable to the site by road
- The method can cope with un-decomposed matter, such as branches, which is likely to be entrained in the sediment
- An appropriate backhoe will be able to cope with the range of sediment consistency likely to be encountered in the lake bed
- The method produces the driest sediment and so minimises the amount of water that would be removed from the reservoir and subsequently transported

Prior to dredging operations, the reservoir surface would be cleared of floating vegetation such as water grass, fallen trees and bamboo which was observed during the reconnaissance. To minimise truck movements and to make transport easier the green waste will be chipped/shredded prior to transport.

Sediment Transport to the Disposal Area

The transport of the wet dredgings from the dredger to the selected disposal sites involves transport from the dredger to the shore and then transport from the shore to the disposal areas.

Transport from the dredger to the shore can be carried out by pumping into a floating pipeline or by mud hoppers propelled by tug. At Hillsborough Dam the length of floating pipeline could be up to 1.2km. This option was rejected at an early stage because of the likelihood of high concentrations of un-decomposed vegetation in the sediment which could cause blockages.

For disposal from the shore to the disposal areas a combination of pumping to buffer lagoons and trucking from the buffer lagoons was favoured at first. However, it was learned subsequently that the proposed site for the buffer lagoons would not be available and an all trucked option was selected.

ENVIRONMENTAL LEGISLATION

As part of its commitment to developing a national strategy for sustainable development, the Government of the Republic of Trinidad and Tobago enacted the Environmental Management Action (Act No. 3 of 2000), which created the Environment Management Authority (EMA). This is an independent body governed by a ten-member multi-disciplinary board, appointed by the President of the Republic of Trinidad and Tobago. This body assumes sole responsibility for environmental management and protection of the natural resources of Trinidad and Tobago.

The goal of the National Environmental Policy is the conservation and wise use of the environment of Trinidad and Tobago to provide adequately for meeting the needs of present and future generations and enhancing the quality of life.

The Policy recognizes the linkages among the human resource, natural systems and development processes and the competition for use of the same resources by different interests. It offers a framework for the management and use of resources to yield the sustainable benefit for the population.

In order to carry out the desilting of Hillsborough Reservoir a Certificate of Environmental Clearance is required from the EMA, with the extent of environmental impact assessment required stipulated by the EMA.

SILT DISPOSAL ISSUES

The disposal of silt was problematical as there is little flat land on the island and in particular in close proximity to the dam site. Disposal at sea was rejected at an early stage owing to the presence of a marine reserve and potential impact on beaches and tourist facilities. Moreover, the potential for spreading silt on agricultural land was also limited as there is little large scale agriculture practised on the island today. The total area under agriculture was estimated at 5,872ha in the 1982 Agricultural Census of which 70% were considered to be small holdings averaging less 2ha.

A total of 14 potential sites were identified from the 1:10,000 mapping as having the potential to receive sediment. The distances from the dam site varied from 150m to 18km and the areas from about 1ha to 2 ha.

In order to determine the best sites, a ranking system was developed on the basis of the following factors; proximity to the dam site, access to the disposal area, environmental / social impacts, area available for disposal.

Each site was ranked on the basis of a rating for each of the above factors from 1 (unfavourable) to 5 (most favourable). The maximum score possible was 18 and sites which achieved a score greater than 50% (9) were considered as suitable for sediment disposal. Three sites achieved the threshold.

However, only one of the three sites was available for the disposal of silt owing to pre-existing agreements or the proximity to a public leisure facility. Thus only one site, about 5km from the dam site was available for disposal. This site is an existing solid waste landfill site and thus silt disposal would not contribute to further degradation of the area.

IMPROVEMENTS IN RESERVOIRS

Arrangements for local farmers to collect silt for use on their small holdings are intended to be implemented.

PROPOSALS FOR FUTURE CATCHMENT MANAGEMENT

Siltation will continue to reduce the reservoir capacity. In order to minimise the need for regular dredging of sediment from the reservoir, action should be taken to reduce the quantity of silt entering the reservoir. Any measures that are implemented in the catchment are likely to require continual long-term maintenance if they are to remain effective in reducing the ingress of silt. If there is no commitment to the long-term upkeep of these measures then a regular dredging operation will be required and would be the most sustainable approach to maintaining storage capacity.

Potential measures to control the ingress of silt would include catchment management, control measures at the head of the reservoir at the inlets from the various streams and implementation of erosion control measures higher up in the catchment.

The primary catchment management measure would be to prevent vigorously the establishment of any new tracks in the forest. The ban on logging should also be enforced vigorously as this activity is the chief cause of establishment of new tracks and general disturbance of the catchment.

Following dredging of the inlets to the reservoir, gabion baskets could be installed across the inlets to act as silt traps. The areas behind the gabions will fill up with silt in time and the areas will need desilting from time to time if they are to remain effective.

Erosion control measures which should be implemented in the catchment would include:

- Stabilising the surface of the slipped mass at slope failures in cuttings
- Establishing vegetation on cut slopes and the scarp faces of old slips
- Providing effective drainage on the existing tracks and remnants of the Castara Road with appropriate silt traps
- Blocking off existing erosion gullies and installing check structures along these routes.

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