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# JOHN COMPTON DAM DE-SILTING AND REHABILITATION PROJECT

# John Compton Dam Rehabilitation Plan

**Submitted to:**
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REPORT

**Report Number: 1404142**

Golder Associates

# Executive Summary

The Government of Saint Lucia (GOSL), based on a grant from the Caribbean Development Bank (CDB), financed this project to restore the water supply from the John Compton Dam (JCD). This study, named the *JCD De-Silting and Rehabilitation Study*, was awarded to Golder Associates Ltd. and its partners on September 24, 2014 (Contract Effective Date). The contract is being administered by the Saint Lucia Water and Sewerage Company Incorporated (WASCO).

The overall goal of the John Compton Dam Rehabilitation Plan is to provide sufficient active water storage in the reservoir for a reliable water supply of up to 10 million imperial gallons per day (IMGD) from JCD, and to implement long-term management measures for maintaining water supply reliability into the foreseeable future. The potential for long-term water supply growth is also considered in terms of increasing the storage by raising the dam or equivalent measures. The plan addresses social, gender, environmental and economic impacts, and accounts for resiliency requirements to manage natural hazards and climate change.

The water storage capacity of the reservoir at JCD has been compromised since it was originally constructed in 1995. The original storage capacity was 3 million $m^3$. As of October 2014, there were at least 1.5 million $m^3$ sediment accumulations, of which 1.1 million $m^3$ or 75% of the sediment is within the reservoir below the spillway elevation of 101.5 m. The remaining 0.4 million $m^3$ or more is deposited on the upstream beach above the spillway elevation. About 2/3 of all the sediment was deposited as a result of landslides triggered during Hurricane Tomas in 2010. Additional sediment has been deposited further upstream, but has not been measured.

The reservoir sedimentation coincides with a period of 30 years with relatively adverse climate conditions resulting in 9 of the 10 worst dry season droughts, based on an analysis of precipitation records dating back to 1890. The drought of 2001, estimated as the 100-year drought, is the worst drought on record. By comparison, the 2014 drought that required water rationing was equivalent to a 10- or 20-year drought.

Sediment has covered one of the two JCD water supply intake ports. The lower intake port is currently covered by 3 m to 4 m of clayey organic silt sediment. The remaining upper intake port has access to the top 6.5 m of water in the reservoir. Below this port, the water in the reservoir is "dead" storage because it is not accessible at the intake elevation. The resulting water supply reliability is about 37%, implying that water rationing is needed in most years during the dry season, most likely in the months of March through June. The remaining operating life of the dam is about 20 years, assuming a year-round water abstraction rate of 6 IMGD plus the historical sedimentation rate.

A variety of options were considered for restoring the water supply and extending the operating life of the dam:

- Alternative water sources to fully replace JCD are not yet proven, although some alternate sources may help to augment the existing water supply from JCD; the alternate water sources include: loss management options to reduce non-revenue water, importing water from other countries, desalination of sea water, groundwater resources, and constructing a new water supply dam along a different river;

- Raising the spillway, as suggested previously by other consultants, is not recommended because it will not restore the water supply and may further reduce the dam safety which is currently less than the original design;
- Flushing sediment from the reservoir is not feasible, because additional downstream sedimentation is environmentally undesirable, there is not enough surplus water to support a reservoir drawdown for flushing the sediment, and because the dam is not equipped with the necessary low level gates;
- Upstream watershed restoration works, such as landslide stabilization, will not address the sediment that has already accumulated in the reservoir, but may help to manage future sediment loading;
- Excavating the upstream sediment beach would not restore the water supply, and would likely result in environmental impacts due to new road construction through the natural tropical rainforest;
- Dredging of the reservoir sediment with a suction dredge with appropriate turbidity controls would restore the water supply by removing sediment near the lower intake port, and could be used to further remove the sand sediment from the upper reservoir areas in anticipation of future storm events equivalent to Hurricane Tomas; a suction dredge is preferred to other types of dredging (e.g. clam shell) that would likely result in excessive turbidity near the intakes;
- Storing emergency water at an off-site location may be a feasible option to restore the water supply in combination with dredging, but is relatively expensive and would require a large parcel of (flat) land that would already be developed for other purposes;
- Raising the dam (and spillway) is a viable option to increase water abstraction at JCD if the problem of reservoir sedimentation is addressed, and will provide an opportunity to restore the dam safety; and
- Constructing a second dam downstream of JCD may also restore the water supply if sediment cannot be managed near the existing intakes.

An assessment of benefits of costs was used to compare a short list of key options to de-silt the reservoir. The assessment priorities focused on restoring the water supply at a reasonable cost, providing management measures for long-term sedimentation, avoiding environmental impacts where possible, and facilitating further measures to enhance the water supply from Roseau River. The assessment results provide a basis for selecting a preferred option.

The preferred JCD De-Silting and Rehabilitation Plan is to dredge sediment from the reservoir, reinstate the lower intake port, deposit the sediment in a nearby Sediment Deposit Area (SDA), and manage emergency water sources at the Vanard and Ravine Poisson river intakes to further reduce the frequency of water rationing. Finally, WASCO should implement the Cul-de-Sac off-channel reservoir as an emergency water source in the style of a stand-pipe operation for on-site distribution from a portable water treatment plant (i.e. water not pumped to the water treatment plant). In addition to the water supply measures, repairs should be made at JCD to reinstate the accelerometers and survey pins for monitoring settlement. Restoration of the low level intake may also be possible after initial de-silting near the dam, but this work will need to be considered with other planning initiatives such as hydropower development. Dam safety inspections and reviews will need to occur on a regular basis for both JCD and the SDA containment dyke, as per international standards.

This plan is expected to improve the water supply reliability to 90%, equivalent of operating the original design capacity of 10 IMGD water abstraction year-round without water rationing in most years. Rationing may still be required once every 10 years on average.

Several options for sediment disposal were considered, of which the Old Laydown Area from the original dam construction is expected to have sufficient sediment storage capacity, is economically efficient, and is least disruptive in terms of environmental, gender, and social issues. The ultimate capacity of the Sediment Disposal Area (SDA) is about 2 million $m^3$. Releasing the sediment to the downstream Roseau River was also considered, but stakeholders from the Water Resources Management Agency (WRMA) expressed a strong desire to avoid downstream releases due to environmental concerns.

The majority of the selected plan is to de-silt the reservoir. The plan will involve the following activities to remove sediment from the reservoir and place it in the SDA:

- Hauling dredge equipment to the dam via Millet Road (or another method proposed by the contractor);
- Installing a silt curtain near the reservoir upper intake. Implementing other contingency measures at the T.R. Theobalds Water Treatment Plant (WTP) to protect the water supply from high turbidity during dredging;
- Dredging the reservoir sediment from a barge during the wet season from July through November to avoid drawing down the reservoir;
- Removing woody debris from the reservoir as dredging proceeds;
- Pumping dredge slurry via a 1.5 km pipeline to the SDA;
- Containing dredge slurry at the SDA by constructing a starter dyke followed by constructing and raising the containment dykes, including a decant structure, filters, drains, and erosion protection;
- Releasing acceptably clean water to the river via a water decant structure and appropriate sediment control measures;
- Re-activating the lower intake port after sediment is cleared from the face of the dam; and
- Managing the deposition area to separate usable material for dyke construction and potential future re-use at off-site locations.

Dredging should start near the dam face to daylight the lower intake port. It will be necessary to remove about 7 m of silt to 78 m for the lower intake port to operate without high turbidity. This elevation is also equivalent to the low level (riparian) outlet elevation. The upstream extent of this silt removal will depend on the characteristics of the sediment in terms of a stable gradient along the bed of the reservoir. Initial estimates are that 80,000 $m^3$ of silt may need to be removed. Once the lower intake port is restored, the dredging operation may be re-allocated by moving the dredge to the beach face about 1.2 km from the dam where the sediment is expected to consist of more than 90% sand. Some of this sand will be necessary to raise the sediment containment area dykes. Afterwards, WASCO will have the opportunity to move the dredge and daylight the Low Level (Riparian) Outlet. The dredging would continue each year to prepare for future sedimentation during large storm events.

The dredging operation must be organized to maintain the uninterrupted use of JCD for water supply. Dredging would therefore be limited to the "wet" season only, from July through November, and would only be allowed if the reservoir was full and spilling from the uncontrolled spillway – so as to avoid unnecessary drawdown of the reservoir at the beginning of a drought. This condition limits the dredge availability to about 80% of the time during the dredge season. When dredging is allowed, the expected utilization of the dredge is about 30% based on 8 hrs per day operation plus non-operating days for maintenance.

Dredging should occur each year on an indefinite basis by removing sediment at a measured pace with a relatively small dredge. The small dredging operation would utilize a common 10-inch size of dredge. By comparison, a large dredge operation could remove all the existing sediment within 3 years, but the capital cost of a much larger 24-inch to 30-inch dredge is expected to be almost triple the cost of a small dredge. At the same time, a small dredge operation will likely provide permanent local employment while also providing flexibility to respond quickly to future storms. By comparison, a large dredging operation would require time to remobilize after a future storm eventually buries the lower intake port again. Instead, a small dredge operation would simply need to shift the location of the operating barge on an emergency basis. The intake port could be restored within about 21 days during an emergency, depending on the number of hours per day that the small dredge is operated. This quick response time is important because loss of the lower intake port could potentially leave WASCO with only 40 days water supply at an abstraction rate of 10 IMGD. A large dredge would not likely be available for shipping and mobilization to daylight the intake within 40 days.

The selected SDA is sufficient for about 20 years of dredging 0.1 million $m^3$ per year sediment removal. The annual sediment removal rate for dredging is based on a sediment budget to account for the size of the dredge, the expected utilization, and the potential for future sediment. Sediment re-use (such as a gravel mining operation) has the potential to extend the life of the SDA to about 30 years. The availability of clean sand for re-use is expected to be up to 50,000 $m^3$ per year. A business case for re-use has not been developed, but would likely include construction of a new access road to the SDA from Dame de Traversay plus further road improvements through Millet. The detailed design and environmental and socio-economic impacts of a new access road have not been included in this report because a new access road is not currently proposed.

An aggressive project schedule is proposed to begin dredging in 2015 prior to the start of the next dry season, subject to funding and contracting arrangements. It is expected that separate contracts will be let to an initial dredging contractor, followed by a second contract for long-term dredging operations, another contract for engineering support during construction, and separate contracts for other aspects of the work.

The vulnerability of this plan to changing climate conditions was evaluated to ensure that WASCO is implementing solutions that will provide a robust and resilient basis for the future water supply. The present climate cycle includes reduced rainfall compared to historical conditions, but available climate projections suggest that rainfall may be further reduced over the next 80 years. The recommended plan is robust in terms of the current drought-frequent climate cycle, but water supply reliability may be eroded over the coming decades if rainfall is further reduced by more than 20%, an upper limit of climate change for most available climate predictions. Future rainfall reductions in the span of 40 years to 80 years may result in water rationing every 5 to 10 years, based on a 20% reduction in rainfall during the dry season. Therefore, alternative water sources will need to be developed to augment the JCD if the climate continues to trend toward less rainfall in the future. However, JCD should continue to be an economical and high quality water source.

A detailed Environmental and Social Impact Assessment and Environmental and Social Impact Assessment and Management Plan for the proposed works are included as part of this report. In summary, the project is expected to result in economic opportunities for employment, and avoid gender-related impacts associated with disturbing subsistence farming areas. Residual environmental impacts may include disturbance to existing vegetation and associated wildlife habitat by clearing the selected sediment deposit area (SDA) for long-term sediment management. The impacts will be mitigated as possible by minimizing the footprint of the SDA and by undertaking vegetation clearing activities outside the breeding season (i.e. the dry season) for species such as the Saint Lucia Amazon (Jacquot Parrot) and the Saint Lucia Black Finch, both of which have potential habitat in the vicinity of the SDA. Bird watching tours may also be affected by developing the SDA near established trails. Reduced spillway flow will also be a necessary impact to restore the water supply during the dry season, but a minimum downstream flow of about 10 L/s is expected to be maintained as a result of water releases from the SDA.

Finally, additional management measures are also recommended:

- A Traffic Management Plan is recommended to manage potential increases of local traffic to and from the dam.
- A Dam Safety Plan is recommended for WASCO to maintain dam safety in the future.
- Recommendations are provided to re-instate dam instrumentation.
- Geohazard mitigation recommendations are provided to further protect the JCD pump house.
- A Source Water Protection Plan (SWPP) is recommended to help manage the source water quality and sediment yield from the catchment upstream of JCD. This report describes an initial plan developed with the Department of Forestry. The SWPP will need to be managed by Forestry, in cooperation with WASCO.
- An Extreme Weather Management Plan (EWMP) is provided as part of this project to describe the emergency response measures during extreme weather, to document the rules for triggering water rationing after the lower intake port is re-activated, to define the methods of water rationing, and to document how emergency water sources will be used.
- An Operating and Maintenance (O&M) Plan is provided in Appendix O.

The Rehabilitation Plan will support a future plan to raise the dam for the purposes of restoring the dam safety and increasing the JCD water abstraction from 10 IMGD to 12 IMGD. The environmental consequences of raising the dam are expected to include: disturbances at additional rock borrow sources along the valley (similar to the original dam construction); additional flooding along the upstream valley; and reduced downstream flow with associated ecological and socio-economic responses along the river. The reservoir may not spill in some years after the water supply is increased to 12 IMGD.

Raising the dam is recommended to address dam safety considerations, subject to future engineering investigations. The existing flood wall is not sufficient for the 10,000 year flood, which represents the original design basis for the dam. Halcrow (2011) had recommended that the existing flood wall should be raised from 5 m to 6.2 m. Golder recommends that the flood wall should be further raised to 6.7 m, with rock fill to buttress the concrete wall. The wall could be raised as part of a design to raise the dam. A design to raise the dam requires additional investigations and engineering beyond the scope of the current project.

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# 1.0 INTRODUCTION

The Government of Saint Lucia (GOSL), based on a grant from the Caribbean Development Bank (CDB), financed this project to restore the water supply from the John Compton Dam (JCD). This study, named the *JCD De-silting and Rehabilitation Study*, was awarded to Golder Associates Ltd. and its partners on September 24, 2014 (i.e. the Contract Effective Date). The contract was administered by the Saint Lucia Water and Sewerage Company Incorporated (WASCO).

The Terms of Reference (TOR) provided in the Request for Proposal (RFP) noted that many landslides have occurred within the reservoir catchment area as a consequence of extreme rainfall events (i.e., Hurricane Tomas in October 2010 and a low-level trough in December 2013). The RFP notes that sedimentation of the reservoir has covered the lower intake port, and a sediment beach has advanced from the upstream portion of the reservoir towards the dam. The storage capacity has decreased significantly due to the sedimentation. The reduced capacity of the reservoir is of serious concern to the GOSL and WASCO because the JCD is the primary water source for the north part of the island where a majority of the urban population resides and where most of the tourism properties are located. Several recent studies have made a variety of recommendations, but have not provided a holistic solution to the water security concerns.

The objective of this technical assistance was to identify a de-silting and rehabilitation plan based on a comprehensive approach to provide a sound technical, environmental, and socio-economic solution for a reliable water supply. The potential for long-term water supply growth will also be considered in terms of increasing reservoir storage by raising the dam or equivalent measures. The plan must also account for resiliency requirements to manage natural hazards and climate change.

The challenges of water availability and reservoir sedimentation are described in detail as part of this report. The impact of droughts on the water supply will be described as part of the *Water Supply Assessment*. The impact of reservoir sedimentation is described as part of the *Reservoir Sediment* section of this report. The *Water Management Options* are described and a benefit-cost assessment provides the rationale for selecting a preferred de-silting and rehabilitation plan.

Other water supply challenges, such as dam structural issues or non-revenue water (NRW) loss management, are not part of the scope of this project. They will be addressed separately by WASCO.

The scope of services includes:

1) Collection and review of available information to characterize site conditions;
2) Stakeholder consultations;
3) Consideration of all possible options to restore the water supply;
4) Initial assessment of the potential impacts from environmental, social, and economic perspectives, and water supply vulnerability to natural hazards and potential climate change;

5) Develop a preferred JCD Rehabilitation Plan which includes:
   a) Designs, specifications, and cost estimates;
   b) Environmental and Social Impact Assessment for the proposed works, and Environmental and Social Management Plan (ESMP) during both construction and operational phases of the project; and
   c) Extreme Weather Management Plan (EWMP) during both construction and operational phases of the project.
6) Develop a tender package for procurement of the selected de-silting and rehabilitation plan; and
7) Develop an Operational and Maintenance System and Procedures manual.

# 2.0 PROJECT SETTING

## 2.1 Location

Saint Lucia is a small volcanic island in the Antillean Archipelago of the Eastern Caribbean (see Figure 1). The area of the island is 616 km$^2$, and it is dominated by a rugged topography characterized by steep valleys separated by narrow ridges that can exceed 900 m elevation. The island has 37 river systems, the largest of which is the Roseau River with a watershed area of about 48 km$^2$ (Towle et al. 1991). The John Compton Dam (JCD) is situated along the Roseau River near the village of Millet in the central portion of the island. The JCD impounds the Roseau Reservoir with an upstream catchment area of approximately 15.3 km$^2$.

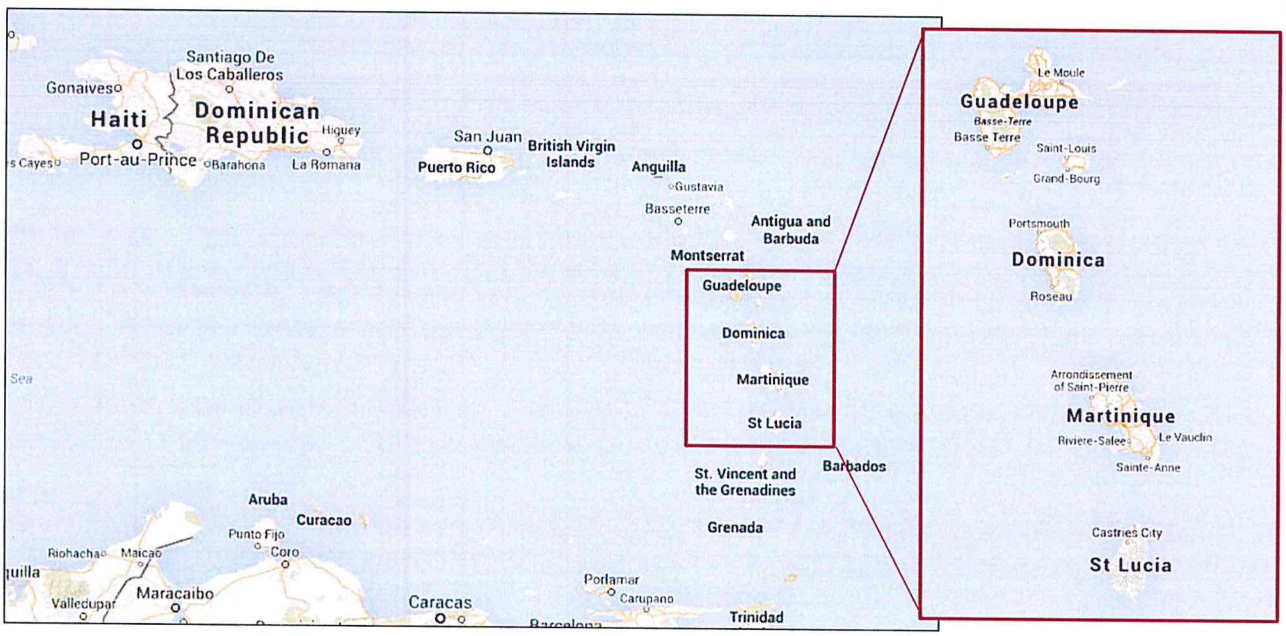



*Figure 1: Location of Saint Lucia in the Windward Islands*

## 2.2 Geology

The Antillean arc of Caribbean islands is geologically young, and is predominantly of volcanic origin within the past 50 million years. The oldest rocks are largely rhyolite, andesite and various basalt lavas which can be found on the surface at the north and south extremes of the island. Additional clastic deposits are found in the central part of the island near JCD. Other calcareous deposits are due to coral reefs which formed about 25 million years ago when the Lesser Antilles were submerged.

## 2.3 Seismicity

Saint Lucia lies in a transition zone where the rate of seismic activity is increasing. The Seismic Research Centre in Trinidad and Tobago reports that there have been at least 5 swarms of shallow earthquakes in Saint Lucia over the past 100 years, clustered in 1906, 1986, 1990, 1999, and 2000 (SRC, 2009). A review of seismological data from Gutenberg and Richter indicates several historical earthquakes with magnitude 7.0 to 7.7 on the Richter scale within 100 km of Saint Lucia (SRC, 2009). The area falls within "Zone 3" which typically has a maximum ground acceleration of 0.33g. However, the dam construction report by Stanley/Klohn-Crippen of August 1996 quotes a 1990 study by the Seismic Research Unit of the University of the West Indies which recommends a Maximum Credible Earthquake (10,000 year return period) of 0.51g.

## 2.4 Climate

Saint Lucia's climate is tropical maritime, characterized by average temperatures ranging from 26°C to 32°C and an average relative humidity of 75%. Rainfall patterns have seasonal variability, with more of the precipitation occurring in the "wet" season between June and November. Saint Lucia is affected by cyclonic weather systems between June and November. The "dry" season is generally from December to May when prolonged drought is common along the coastal regions. A sharp rise in relief toward the interior of the island results in orographic lifting, often generating higher rainfall accumulation compared to the coastal region.

The Millet area near JCD receives about 3,450 mm per year rainfall (long-term average from 1890 to 2014), and as little as 2,500 mm in 2001. The annual rainfall records at Millet are shown on Figure 2, estimated from monitoring data at Millet and supplemented by correlating monthly rainfall at Castries. About 55% of this precipitation runs off the landscape, based on a water balance analysis. Rainfall on the reservoir is partially offset by lake evaporation at an average rate of 5 mm per day (Leonce 1978), resulting in about 1 m evaporation during the dry season when the reservoir is sometimes drawn down during a drought. Additional climate and hydrology information is provided as part of the *Water Supply Assessment*.

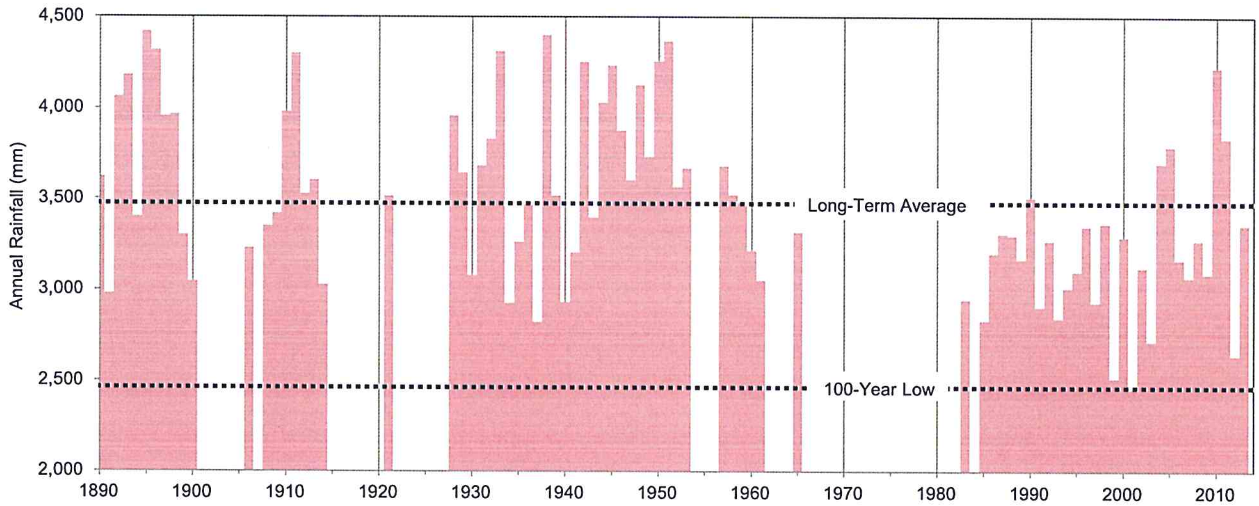



*Figure 2: Annual Precipitation at Millet (1890-1995 estimated from Castries)*

Cyclonic systems have historically affected Saint Lucia. There have been three extreme weather events since the dam was first constructed: Debby (1994), Tomas (2010), and the Christmas Storm (2013). Hurricane Tomas was the largest documented hurricane to hit the island and is commonly referred to as the worst national disaster to hit the island in current memory. The return frequency of a similar event to Hurricane Tomas has been estimated to be in excess of a 100-year event, with some analysts classifying it as a 180-year event based on the 24-hour rainfall accumulation (ECLAC, 2011).

Hurricane Tomas hit the island on October 31, 2010 immediately following a prolonged drought. Heavy rains generated mudslides and landslides across the island and made roads impassable. Estimates of the 24-hour rainfall associated with this hurricane system range from 500 mm to 700 mm (NHC, 2011). The water supply from JCD was offline for approximately two weeks after the event, due to damages at the dam.

Saint Lucia was more recently affected by an unseasonal low-level trough system (Christmas Eve Storm) on December 24 to December 25 of 2013, which brought torrential rains and strong winds over a 24-hour period. Saint Lucia suffered massive infrastructure damage and several parts of the island were impacted by landslides and flash floods. Estimates of the 24-hour rainfall associated with this system range from 200 to 350 mm across the island (GOSL and World Bank, 2014). General consensus among government officials is that the infrastructure damage from this storm was, in many cases, as bad as Hurricane Tomas.

## 2.5 Environmental and Social Setting

Information related to the environmental and social setting was compiled for the Roseau watershed based on existing literature, available datasets, an initial site visit during the week of October 29 (2014), and stakeholder interviews. The stakeholder consultation consisted of one-on-one interviews, a stakeholder workshop in October, and a second stakeholder workshop in January.

## Stakeholders

Key stakeholders consisted of government agencies, water supply customers, and Anse La Raye region communities. The stakeholders included:

- Ministry of Infrastructure, Port Services and Transport;
- Ministry of Finance, Economic Affairs, and Social Security;
- Ministry of Physical Development, Housing and Urban Renewal;
- Department of Planning and National Development;
- Ministry of Tourism, Heritage and Creative Industries;
- Ministry of Agriculture, Food Production, Fisheries Cooperatives and Rural Development;
- Ministry of Health, Environmental Department;
- Ministry of Sustainable Development, Energy, Science and Technology;
- Water Resources Management Agency (WRMA);
- National Water and Sewerage Commission;
- Ministry of Social Transformation and the Division of Gender Relations;
- Hotel and Tourism Association representatives;
- Millet Development Committee representatives; and
- Saint Lucia Distillers Ltd.

The stakeholder workshops are documented in Appendix A. Additional information from one-on-one interviews is provided as part of the *Social and Gender Impact Assessment*.

## Socio-Economic Setting

The social setting within the local and regional socio-economic study area is summarized below:

- The local communities with the potential to be directly affected by the Project are found within the Anse La Raye region and include: Millet, Caico, Tete Chemin, Venus, Vanard, Derandeaux, Roseau, and Jackmel.
- The Millet and Roseau Rivers are valuable assets to the local communities for drinking water for livestock and irrigation. During water shortages the river is also used for potable water, bathing, laundry and other household uses.
- There are two primary schools, a health center, post office, and a catholic church associated with the Jackmel and Millet areas.
- Transport is primarily via mini bus, with no scheduled times of departure or arrival, or walking.
- The economy in Anse La Raye is considered the least viable on the island. The majority of the population of the region engages in fishing and farming. Tourism is adding a vital economic input for the region.

- Trade and commerce within Anse La Raye is virtually non-existent. Salaried persons are involved mainly in teaching or civil service outside the village. The primary schools offer employment in the village for a small number of people. Some residents travel to the capital city of Castries for work.
- Anse La Raye region demographics summary, based on information obtained from the 2010 census:
  - Population of 6,247 people, of which 3,190 are males and 3,057 are females;
  - Unemployment of 24.5%, 23% for males and 27% for females;
  - Total working population: of 2,995, 1,719male, 1,276 female;
  - Agriculture, forestry and fishing industries employ 293 males, 121 females;
  - 17% of males are employed in agriculture, forestry and fishing, and
  - 9% of females are employed in agriculture, forestry and fishing.

## Aquatic Environment

Saint Lucia's freshwater and nearshore marine ecosystems are home to a variety of aquatic life. The island's reefs, although not extensive, are critical to tourism and the nearshore fishery. Roseau Bay, into which the Roseau River drains, is a prime fishing site for seine fishers. The river ecosystems of Saint Lucia are home to a variety of freshwater fish species, as well as invertebrate species such as the freshwater shrimp, commonly known as 'crayfish'. Further information regarding the hydrology of the Roseau watershed is provided as part of the *Water Supply Assessment.*

Pollutant sources in the Roseau watershed are primarily sediment (as a result of landslides and agriculture), sewage, and agro-chemicals. Solid waste disposal has also been identified as a threat to water quality (Government of Saint Lucia, 2006). Sedimentation downstream of the dam was noted as an ongoing issue during the initial stakeholder workshop. Concern was expressed by representatives of the WRMA that the downstream Roseau River is already heavily silted due to downstream agricultural activities. River siltation is expected to affect both freshwater and offshore aquatic life. In particular, offshore fishermen rely on aquatic habitat in Roseau Bay, as noted above, where the health of coral reefs and other habitat may be affected by additional sediment delivery from the Roseau River.

## Terrestrial Environment

There are seventeen vegetation types found on St Lucia that are used to classify the island's ecosystems (Graveson, 2009). Vegetation types found within the Roseau watershed are summarized on Figure 3. The area to the south and east of the Roseau Reservoir are within the lower montane natural tropical rainforest. To the north of the Roseau Reservoir the watershed consists of a mixture of human influenced vegetation ecosystems. Skirting the lower montane rainforest is mixed farming and intensive farming land use areas. Closer to the coast there are more areas of intensive flatland agriculture and areas of urban settlement (SLFD, 2002).

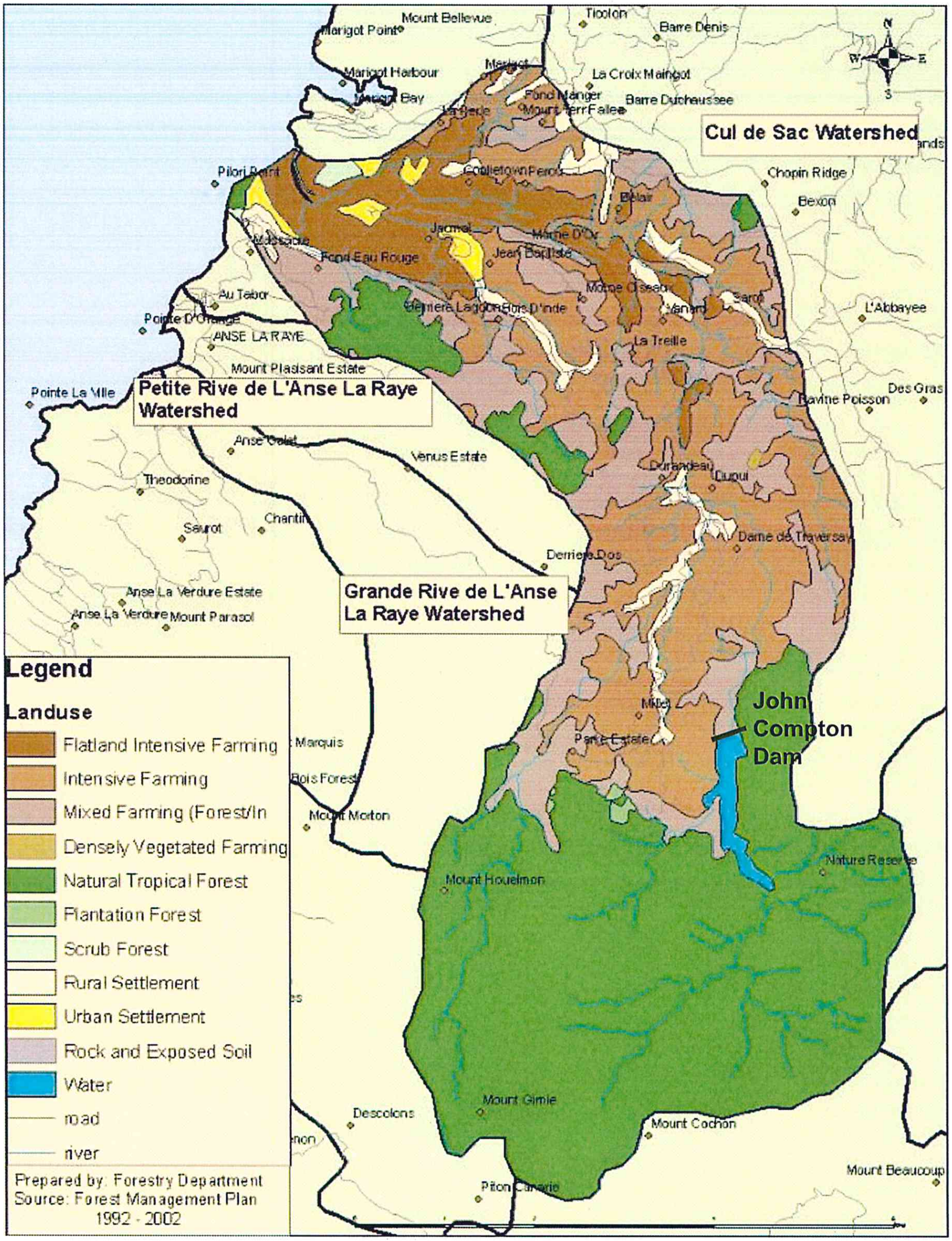



*Figure 3: Roseau Watershed Vegetation Communities*

## Wildlife

Numerous wildlife species can be found within the Roseau watershed. Of the many wildlife species in the area, several have been deemed critical or priority for protection in Saint Lucia in the 2009 study Management of Critical Species on Saint Lucia, Species Profiles and Management Recommendations (Morton, 2009). The species identified in this study were selected as flagship or umbrella species to protect and bring awareness to whole ecosystems. A number of criteria were used to identify the species at high to extremely high risk including: endemicity, declining or very restricted populations and/or ranges and the severity of the threat to their survival. Some of these species are listed globally as vulnerable (as per International Union for Conservation of Nature (IUCN) red list), while others are recommended to be listed as Vulnerable or Near Threatened. Table 1 summarizes the species and relative threat category.

The greatest threat to vulnerable and endangered species in Saint Lucia is habitat modification and destruction. High population density and increased (tourism and residential) development are the key drivers for habitat loss (CBD, 2009). Predation from invasive species is also a threat to species considered critical or priority.

Invasive species are defined as organisms (plant, animal, fungus, or bacterium) that are not native and have negative effects on the local economy, environment, or health. For example, the invasive Shiny Cowbird (*Motothrus bonairensis*) preys on the nests of the Saint Lucia oriole. The Asian mongoose (*Herpestes javanicus)* is a very efficient predator that was introduced historically to manage snakes; it preys on small reptiles such as the Saint Lucia pygmy geko (*Sphaerodactylus microlepis)* as well as on nests of ground dwelling species including the Saint Lucia black finch (*Melanospiza richarsoni*). Other species, such as the African Tulip Tree (*Spathodea* campanulata), invade disturbed areas and are a particular threat to the natural rainforests of Saint Lucia.

**Table 1: Wildlife Species with Habitat Requirements within the Study Area (Morton 2009)**

| Species | Habitat | IUCN Rating | Recommended Threat Category | CITES | Wildlife Protection Act 1980 (amended 2001) |
|---|---|---|---|---|---|
| *Saint Lucia Pygmy Geko* | Lower Montane Forest | Not evaluated | Vulnerable | Not listed | Not listed |
| *Saint Lucia Fer-de-Lance* | Widely varying including: deciduous seasonal, semi-evergreen, and lower montane rainforest | Not evaluated | Vulnerable | Not listed | Not protected (Schedule 3) |
| *Saint Lucia Amazon Parrot* | Canopy of montane rainforest | Vulnerable | Vulnerable | "Appendix 1" | Schedule 1 – Protected Wildlife (Birds) |
| *Saint Lucia Black Finch* | All the forest types in Saint Lucia, but prefers secondary growth | Endangered | Endangered | Not listed | Schedule 1 – Protected Wildlife (Birds) |
| *Saint Lucia Yellow-shouldered Bat* | Humid lower montane forest is the dominant habitat for this species, particularly near streams. | Least concern | Near threatened (nationally) | Not listed | Not listed |
| *Saint Lucia oriole* | Deciduous seasonal forest, semi-evergreen seasonal forest and lower montane rainforest. | Near Threatened | Unknown | Not Listed | Not Listed |

## 2.6 Drinking Water Supply

The Water and Sewerage Company of Saint Lucia (WASCO) is the Island's public water utility, headquartered in Castries. WASCO provides water services to the Island's 176,000 residents and the approximately one million tourist visits annually. WASCO operates the JCD, plus 29 other raw water sources and intakes, 9 water treatment plants, and 80 storage tanks. It has a distribution system estimated to be 800 to 1000 km in length with some pipes dating back to the 1940s. There is a significant level of non-revenue water (NRW) which accounts for approximately 56% of the produced water. NRW is due to leaks and overflows from deteriorating infrastructure, water theft, meter issues, database inaccuracies and billing discrepancies.

Water supply to the northern portion of the island, including Castries and the principal tourism areas, is provided by the T.R. Theobalds Water Treatment Plant (WTP). The primary water source for the WTP is water abstraction from Roseau Reservoir at John Compton Dam (JCD). The JCD was designed to supply 10 IMGD. Key infrastructure locations are illustrated on Figure 4. The pipe alignments were not available.

The water supply from JCD has been augmented in the past by the following additional sources:

- Vanard Intake: This temporary structure has been used to abstract water from the Roseau River downstream of JCD during water supply emergencies. The Vanard intake was heavily damaged by both Hurricane Tomas in 2010 and the 2013 Christmas Eve Storm. Temporary repairs to the Vanard intake consist of sand bags and gabion baskets. This intake is only intended to augment the water supply if there is not adequate supply from JCD.
- Ravine Poisson Intake: This small river intake consists of a concrete structure. This intake is only intended to augment the water supply during an emergency if there is not adequate supply from JCD.
- Millet River Intake: Is another small intake similar to Ravine Poisson, used to augment the JCD water supply. It is known to be unavailable during drought conditions due a dry river bed.

A policy of water rationing has been implemented by WASCO to promote the conservation of water during drought conditions when a water shortage may occur. Rationing was implemented as recently as 2014.

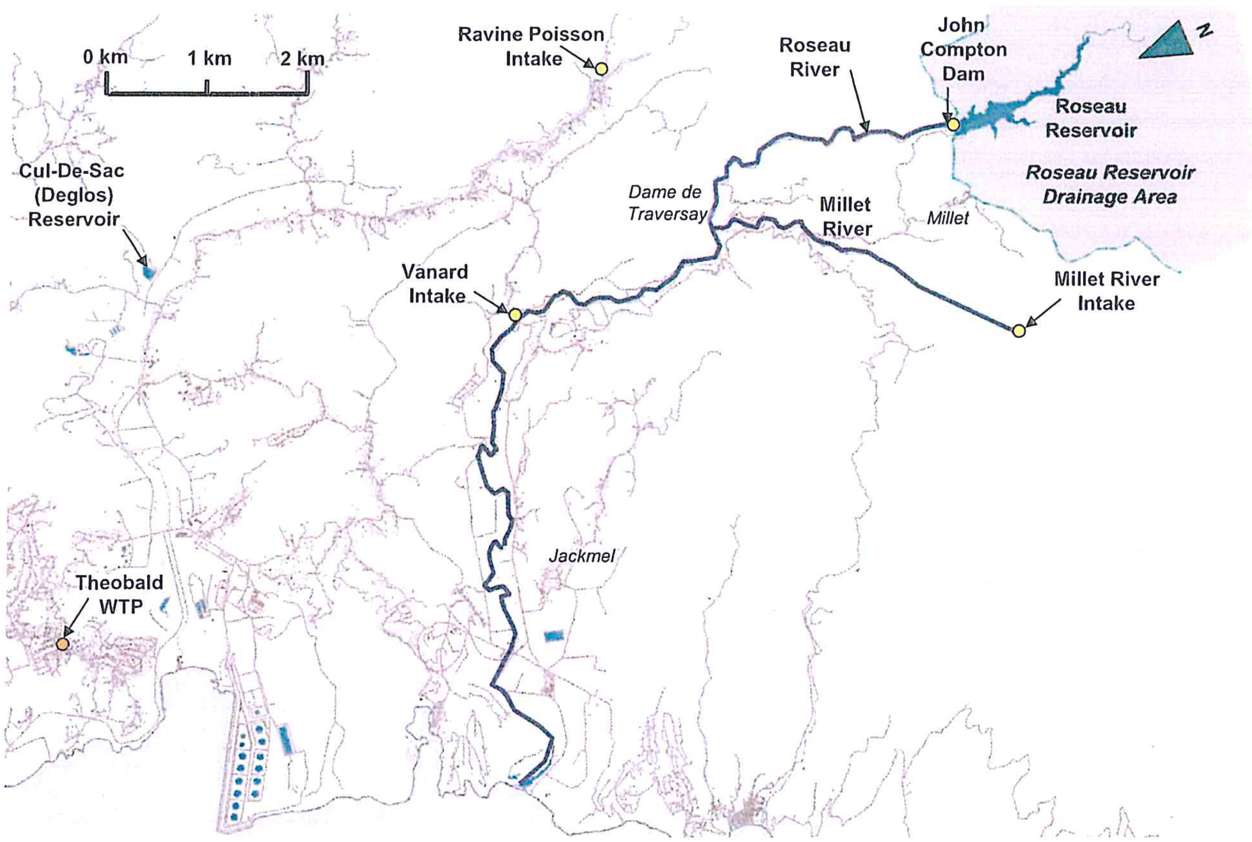



*Figure 4: Location of Selected Water Supply Infrastructure*

## 2.7 Water Treatment Infrastructure

The T.R. Theobalds Water Treatment Plant (WTP) was originally built in 1993 and expanded in 2007 to its present capacity of 10 IMGD. The plant is a conventional treatment process consisting of coagulation, flocculation, sedimentation, filtration, disinfection, and storage.

Coagulant aid chemicals are injected into the inlet line where natural turbulence in the line completes the mixing. There are no mixers on the inlet line. The line splits between the two process lines of the treatment plant where it is modulated by hand at the butterfly valves on the two inlets. The raw water enters the inclined plate settling tank to remove solids. The water then enters the rapid sand filters where further solids are removed. The filters consist of 10 different tanks with anthracite and sand media. The water is disinfected using chlorine in the form of gas and is placed in one of the two concrete-treated water storage tanks. Water is then pumped to the distribution system. The on-site laboratory tests the inlet and outlet water quality, and the waters appear to be a good quality product from a review of the logs.

Following Hurricane Tomas, operators added chemicals to remove iron and manganese from the water. Only coagulant chemicals are currently being used to augment the treatment process as the levels of iron and manganese in the raw water supply have since reduced. After Tomas, the colour of the raw water at the treatment plant had a greenish tinge as a result of chlorophyll being released by decomposing plant material that was blown or fell into the reservoir during the storm. The treatment process is not able to remove the colour but the appearance of colour was temporary.

Current storage at the WTP acts as a buffer for a few hours to support backwash cycles, but does not provide a significant emergency supply. Many water supply operations have storage reservoirs with capacity for 12 hours supply or more.

## 2.8 John Compton Dam Infrastructure

The John Compton Dam (JCD) and ancillary infrastructure consists of the following:

- **John Compton Dam Structure:** The dam structure is a concrete faced rock fill dam or a rock fill embankment with a concrete slab on the upstream face. The crest length of the dam is approximately 175 m and the maximum height is about 40 m. The dam has apparently been designed for a maximum credible earthquake of 8.0 to 8.5 on the Richter scale. A cross-section through the dam and water supply intake is shown on Figure 5. Layout of the dam structure is shown on Figure 6.
- **Roseau Reservoir:** The reservoir for JCD originally extended about 2 km upstream of the dam structure. It had a design storage capacity of 3 million $m^3$ and an active storage capacity of 2.7 million $m^3$ above the lower intake port. The current reservoir conditions are shown on Map 1 in Appendix B, based on recent aerial and bathymetric surveys. The reservoir storage capacity has been impacted by sedimentation since initial construction, described as part of the *Reservoir Sediment* section of this report.

- **Diversion Tunnel/Low Level Outlet:** The diversion tunnel is a 215 m long arched (4.5 m diameter) tunnel that was constructed in bedrock. The diversion tunnel consists of an upstream gate, a concrete plug, a 0.6 m diameter pipe from the concrete plug to the downstream outlet, a riparian outlet, and control valves. The diversion tunnel and outlet are currently inoperable due to sediment blockage at the upstream intake location and damage to the control valve from a landslide that occurred during Hurricane Tomas. A cross section through the diversion tunnel is shown on Figure 7. The upstream gate for the tunnel was designed as a single use structure, to be closed after the dam was constructed. It was not designed to be re-opened.
- **Concrete Spillway:** The uncontrolled spillway has a sill elevation of 101.5 m above mean sea level (masl) and a sill length of 33 m. The concrete lined chute of the spillway on the downstream face of the dam narrows to 20 m at a flip bucket at the downstream toe of the dam. The spillway is active because the reservoir level normally exceeds the spillway elevation.
- **Water Intake:** The water intake is a 914 mm diameter pipe running along the upstream face of the dam with two intakes fitted with screens and 600 mm butterfly valves on a tee from the main line at 82 m and 95 m. The valves have a hand wheel actuator to close the valve and remove the screen if necessary. Screens have an air-line blower system to backwash the system and clear debris. Currently only the upper intake port is available for water abstraction since the lower intake port is covered with sediment.
- **Access Road:** The access road leads to the pump house, dam structure, and boat launch areas. Current access to the dam consists of a paved road through the community of Millet, plus a private gravel access road from the Millet Road to the dam.
- **Pump House:** The pump house is located on the downstream left bank near the face of the dam. It consists of one building and an overhead structure for pumps. The pump house is supplied with 3 phase power from the island power grid. The pumps consist of 5 x 250 horsepower pumps, each capable of 2.5 IMGD or 1,733 imperial gallons per minute.
- **Boat Launch:** There is a boat launch on the left bank near the upstream face of the dam.

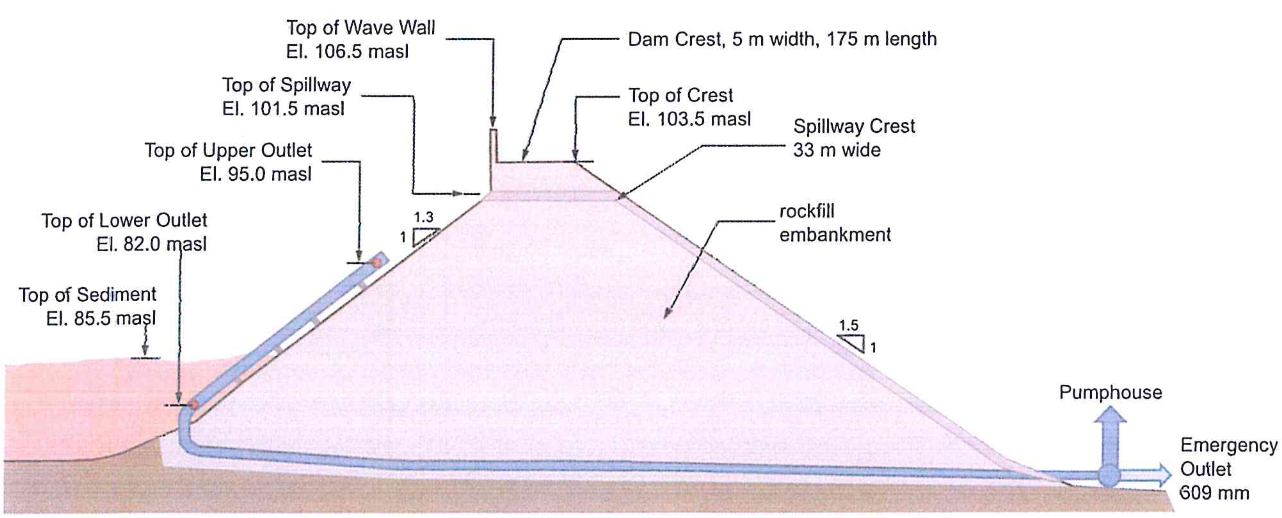



*Figure 5: John Compton Dam Typical Section and Water Supply Infrastructure*


*Figure 6: John Compton Dam General Arrangement (imagery from Golder UAV survey, October 2014)*

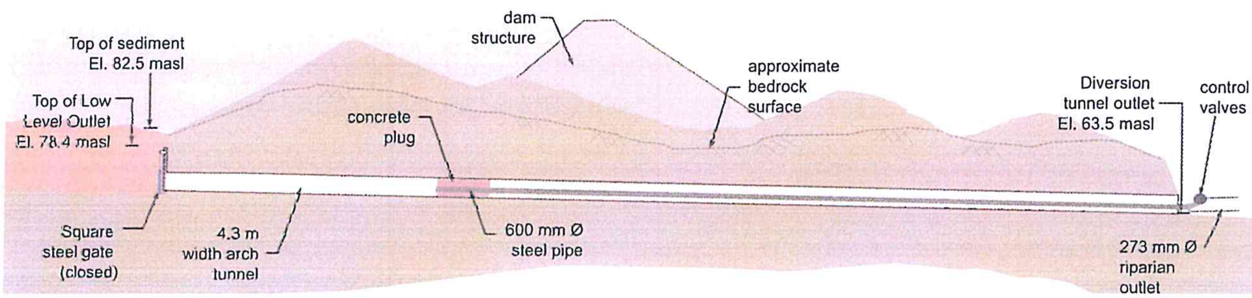



*Figure 7: Diversion Tunnel and Riparian Outlet*

## 2.9 Dam Condition Report

### General Observations

Golder carried out a visual inspection of the dam during the site visit, and interviewed WASCO staff regarding the infrastructure condition and damages experienced during hurricane Tomas. This section provides our observations and comments on the dam from the site visit, but does not describe all of the previous flood damages which have been documented previously by WASCO.

During the time of the site visit (October 28, 2014), the weather was dry and the reservoir was at the level of the overflow spillway. In general, the dam appeared to be in good condition and there had been no noticeable deterioration since the 2010 Dam Inspection by Halcrow in January 2011.

Although the seepage weirs are not serviceable, the toe of the dam at river bed level is clearly visible and there was no measurable seepage. There is no noticeable settlement of the rock fill on the downstream face, of the crest or of the wave wall. The rock at the toe of the dam below the flip bucket of the spillway is jointed but it has a high strength and the joints are tight. There has been no significant erosion of the plunge pool area.

### Spillway

The cavity below the spillway slab has been filled with concrete but the training walls have not been repaired since they were damaged during Hurricane Tomas. We recommend that the training walls be rebuilt as soon as possible as more erosion and cavities can be expected if the spillway experiences high flows before the repairs are completed.

The spillway slab appears to be in good condition and there is no visible differential settlement at the construction/contraction joints. It is important to monitor the cracks and deformation of the spillway slab as differential settlement could lead to failure of the spillway during floods.

We understand that WASCO staff periodically access the spillway crest to dispose of large woody debris when floating logs become snagged by low flow depths over the spillway. Safety measures are installed for staff to securely walk onto the spillway

### Diversion Tunnel and Low Level Outlet

Golder inspected the downstream portal of the diversion tunnel (it was not safe to inspect the whole tunnel as the quality of the air in the tunnel was not known). The downstream portal slopes are stable and did not appear to suffer damage from the landslide that occurred during Hurricane Tomas. The downstream end of the tunnel appears to be in good condition and no significant cracking or deformation is visible in the rock support or to the shotcrete. The valve at the downstream end of the low level outlet pipe in the tunnel is in poor condition. The upstream inlet portal for the diversion tunnel is covered with sediment. We understand that this pipe outlet was installed to draw down the reservoir within 3 days after a major earthquake or if the dam experienced significant problems. It would take a significant effort to repair the downstream valve. A separate study has considered the requirements to reinstate the low level outlet as part of a configuration for hydropower development.

### Pump House

The pump house appeared to be in good working order, including the pumps which are situated outside of the building near the crest of the valley slope along the downstream face of the dam. The pump house was repaired after Hurricane Tomas when it was inundated by sediment and debris. Some damage is still visible to the roof shelter above the outdoor pumps. This damage was caused by large woody debris that was ejected over the spillway during the flood. WASCO employees were evacuated during Hurricane Tomas prior to the damage. According to information provided by WASCO, the dam outage lasted approximately 1 week after the hurricane.

### Instrumentation

The instrumentation at the dam is not functioning and is not being monitored. Recommendations for implementing a dam instrumentation and monitoring plan are described later in Section 7.15 of this report. The original instrumentation shown on Drawing No. PA 2644-346 by Stanley – Klohn Leonoff dated 93/03/01 consists of the following:

- Seepage weirs: These weirs at the downstream toe of the dam were damaged when the training walls of the spillway collapsed during Hurricane Tomas.
- Settlement Monuments/Pins: There are settlement monuments/pins in the top of the parapet wall at the crest of the dam. We understand that WASCO is not conducting settlement surveys of the dam crest, downstream slope or settlement monuments. Spillway Crack Monitors: There are crack monitors across the contraction joints of the spillway slabs/retaining walls. We understand that the original crack monitoring gauges have not been maintained and are not being read.
- Accelographs (or Ground Motion Monitors): There are three accelographs attached to the parapet walls shown on Drawing No. PA 2644-346. These instruments are intended to monitor the shaking of the dam crest and abutments during earthquake shaking. We understand that these instruments have not been maintained and may not be operational.
- Reservoir Staff Gauges: These gauges appear to be in place and are being used.

## 2.10 Dam Safety Considerations

### Previous Dam Safety Report

A dam safety inspection was completed by Halcrow in 2011 after Hurricane Tomas. The dam safety report (Halcrow, 2011) describes that lower portions of the spillway chute training walls were destroyed and a 30 m section of the concrete spillway was undermined during Hurricane Tomas. Both the lower intake port and low level outlet were inoperable. Accelerometers, installed for ground motion monitoring, were non-functional and several survey pins for the monitoring of settlement needed to be restored.

The dam was designed for a Probable Maximum Flood (PMF) of 600 $m^3$/s, as estimated by Klohn-Crippen (1991). Halcrow (2011) re-evaluated the design flow, and estimated that a smaller 10,000 year return period flood event would result in a peak flow of 710 $m^3$/s. Halcrow estimated the peak outflow over the spillway during Tropical Storm Debby and Hurricane Tomas:

- Debby (1994): 540 $m^3$/s, based on routing of the available Debby hyetograph; and
- Tomas (2010): 300 $m^3$/s, based on high water marks along the spillway training walls.

According to the dam safety review conducted by Halcrow (2011), John Compton Dam is able to withstand floods below the 10,000-year return period, without any allowances for wave run up. The original design of the dam did not make any allowances for wave freeboard since the valley is fairly steep sided, which provides some shelter from extreme winds. The current freeboard on the dam is 5 m, selected as a result of routing the design flood through the spillway using a spillway weir flow coefficient of 1.6. Halcrow recommended a freeboard of

6.2 m for a 10,000 year flood event including wave run-up, based on an analysis using a weir coefficient of 1.45. It is the opinion of Golder that a weir coefficient of 1.45 is correct.

### Recommended Freeboard

The 6.2 m freeboard recommended by Halcrow should be increased to 6.7 m, based on a preliminary freeboard assessment by Golder for the 10,000-year flood event.

The current dam and spillway were evaluated based on an estimated increase in the intensity (hurricane category, rainfall amounts, and wind speeds) and frequency of extreme weather events. Hydrology studies outlining the probable maximum flood (PMF) or the 10,000-year flood events for the reservoir and dam are currently not available and the original design reports for the dam have been lost (Halcrow, 2011). In the absence of available hydrology data for flood events, Golder conducted a preliminary hydrology analysis for extreme weather events to determine the extreme flood hydrographs using available rainfall data from stations near the reservoir (Millet and Edmund Forest) and watershed characteristics (e.g., drainage area, vegetative cover, relief).

Probable maximum precipitation (PMP) estimates were developed using the Hershfield Method (Hershfield 1965) and compared with published regional estimates for Puerto Rico (US Weather Bureau, 1961). With the Hershfield approach, the 24-hour probable maximum precipitation (PMP) was estimated between 1,420 mm and 2,470 mm using long-term daily rainfall data at Millet (el. 210 masl) and Edmund Forest (el. 485 masl). As shorter duration rainfall events (6 to 12 hours) are more likely to cause the Probable Maximum Flood (PMF) in small basins, the 24-hr PMP estimates were not used to estimate the PMF. Instead, the appropriate 6-hour PMP estimates for Puerto Rico (US Weather Bureau, 1961) were transferred to Saint Lucia. Published point PMPs for the 6-hour and 24-hour durations are 950 mm and 1,525 mm, respectively. The derived 24-hour PMP at Millet is of similar magnitude, which indicates that the transfer of a moderately up-scaled 6-hour PMP from Puerto Rico to Saint Lucia may be appropriate. A HEC-HMS model (USACE, 2013) was setup with the 6-hr PMP, temporally distributed using the median fourth quartile distribution (NOAA, 2014b). Area reduction factors were not applied as the small basin size suggests that point PMPs may be appropriate.

The estimated PMF peak flow is about 1,160 $m^3/s$, assuming the 6-hr PMP event generates the PMF event. The estimated peak flow for the 10,000-year event is 730 $m^3/s$ (roughly $2/3^{rd}$ the PMF peak). These numbers are comparable with those published in Halcrow (2011). An inflow hydrograph was generated for the 10,000-year event and routed through the reservoir to estimate the peak level and required freeboard. Assuming the reservoir is at the normal operating level (at the spillway elevation) and that the existing storage curve can be extrapolated linearly, the estimated peak water level was estimated to be 107.5 m. Therefore the wave wall would need to be raised to 108.2 m, including an additional allowance for 0.7 m wave run up as calculated by Halcrow (2011).

If the additional freeboard is accomplished by raising the existing wave wall, Golder recommends that the raised wall should be supported by raising the crest of the rock-filled dam. Halcrow also recommended that the training walls along the spillway chute should be repaired and that the scour hole beneath the spillway chute slab should be backfilled. The recommendations have not yet been implemented, except for the backfilling of the scour hole.

# 3.0 RESERVOIR SEDIMENTATION

Extreme weather events have affected the JCD in terms of reservoir sedimentation. Three events have impacted the reservoir since the start of construction: Hurricane Debby in 1994, Hurricane Tomas in 2010, and the 2013 Christmas Eve Storm. These events account for the majority of sediment delivery to the reservoir as a result of landslides near the rim of the reservoir. The landslides and potential future landslides are geological hazards or geohazards that influence the requirements to manage reservoir sediment over the operating life of JCD. The characteristics of this sediment further influences how the sediment should be managed. These geohazards, sediment characteristics, the current sediment volume, and the estimated future sediment accumulation are described in the following sections.

## 3.1 Geohazard Assessment

A geohazard assessment was conducted for this study by Roosevelt Isaac of Strata Engineering (Saint Lucia) to document the source of existing reservoir sedimentation, and to estimate the potential for future sedimentation. The assessment utilized available topographic and soil mapping, aerial imagery, and ground measurements. Potential hazards were categorized based on the slope of the valley wall, with moderate and high hazards for slopes above 33% ($18^{o}$). The hazards that were identified include landslides, rock falls, debris flows, and shoreline erosion. The geohazard assessment report is provided in Appendix C.

In summary, the majority of reservoir sediment is due to landslides and associated debris flows. A total of 21 landslides have been mapped, of which 17 landslides are adjacent to the reservoir. The Forestry department mapped an additional 4 landslides in the upper catchment, all of which are situated along the Roseau River within 500 m of the reservoir. Most of the landslides are associated with steep gullies that provide drainage during a storm. The landslides have resulted in the deposition of larger materials such as gravels and cobbles within alluvial fans near the reservoir. These alluvial fans may be further mobilized into the reservoir, perhaps as debris flows.

The landslides are generally shallow translational slides resulting from rapid infiltration during rainstorms, in particular following a dry period when soil cracks form and allow rapid infiltration. This was the case in 2010 when Tomas occurred after a severe drought. Additional future landslides may be detected near the head of steep gullies where soil creep indicates slope instability.

Future reservoir sedimentation due to landslides is uncertain but likely. The number of additional future landslides is not known with certainty, but there are at least 2 locations along the reservoir with steep slopes along a drainage path that has not yet formed a landslide. In addition to new future landslides, the existing landslide areas are expected to deliver additional sediment to the reservoir where the landslides have formed alluvial fans that may be re-mobilized during a storm.

## 3.2 Sediment Characterization

Reservoir sediment was characterized as part of this study by Strata Engineering (Saint Lucia), in terms of grain sizes, engineering properties, and chemical components. A total of 34 soil samples were collected from different areas of the reservoir during the field investigations from October 17 to November 24, 2014. These soil samples were then tested for various contaminants, as well as for moisture content, particle size distribution, bulk density, shear strength, plasticity index, specific gravity, hydraulic conductivity and mineralogical composition. The sampling methods varied: 4 boreholes were drilled from a raft into the reservoir sediments; 7 test pits were excavated by hand shovel at the alluvial fan of tributaries entering the reservoir and on the upstream sediment beach. Further details of the field investigation are provided in Appendix D.

The reservoir sediment can be characterized as follows:

- Near the face of the dam, the sediment consists of low density, soft, clayey organic silt throughout the sediment deposit;
- In the middle of the reservoir, the sediment consists of sandy organic silt underlain by silty sand;
- At the upper end of the reservoir near the current beach line, the sediment consists of gravelly sand for at least 3 m, underlain by silty sand (more than 90% sand content);
- Sediment located near the mouth of tributaries consists of sand and gravel (more than 95% sand);
- Sediment located on the beach in the upper reservoir consists of sand and gravel (more than 95% sand);
- Organic matter content was 6% to 7% by weight;
- Iron was detected at elevated levels of about 50,000 mg/kg; and
- The sediment contains variable amounts of quartz, plagioclase feldspar, smectite, augite, and halloysite/kaolinite.

## 3.3 Sediment Volume

The sediment volume has been measured on several occasions since the dam was constructed. Most measurements have been based on bathymetry surveys below the water line. The sediment was observed by Klohn-Crippen (1995) after Debby, and then surveyed by Halcrow (2005), Halcrow (2011), DB Sediment (2013), and recently by Golder (2014). An original storage curve was developed by Klohn-Crippen (1991) prior to dam construction. The sediment was surveyed most recently as part of this study by two methods: a bathymetry survey below the water line; and by an aerial survey above the water line using an unmanned aerial vehicle (UAV). The resulting topography and imagery is shown on the map in Appendix B.

As of October 2014, there was at least 1.5 million $m^3$ of sediment accumulated since the start of initial dam construction, of which 1.1 million $m^3$ or 75% of the sediment is below the spillway elevation of 101.5 m. The remaining 0.4 million $m^3$ sediment is deposited on the upstream beach above the spillway elevation. Additional sediment has been deposited further upstream of the original reservoir, but it was not quantified because the original ground topography is not available and the survey did not include all upstream areas.

The progression of sediment accumulation over time is shown on Figure 8, indicating that the three major events led to the majority of sediment deposition in the reservoir:

- Tropical Storm Debby (1994) – 0.15 million $m^3$ (Klohn-Crippen,1995);
- Hurricane Tomas (2010) – 1.06 million $m^3$; and
- Christmas Storm (2013) – 0.18 million $m^3$.

The distribution of sediment within the reservoir is shown on Figure 9. The beach deposit in the upper reservoir extends more than 500 m into the original reservoir, and the lower intake port (at the dam face) is covered with about 4 m of sediment. There is about 19 m of sediment near the dam, and generally about 10 m throughout the reservoir.

Overall, the portions of silt and sand (above the lower intake port, as measured from 78 m) are about 30% silt and 70% sand respectively. The reservoir sediment consists of varying deposits of silt and sand, as characterized by the borehole and test pit field investigations. Silt deposits are located near the face of the dam, and likely extend up to 800 m upstream of the dam. The remaining sediment is predominately sand, with some surficial gravel. The volume of sediment may be changing over time as the low-density silt deposits near the dam gradually consolidate or densify.

## 3.4 Sediment Yield

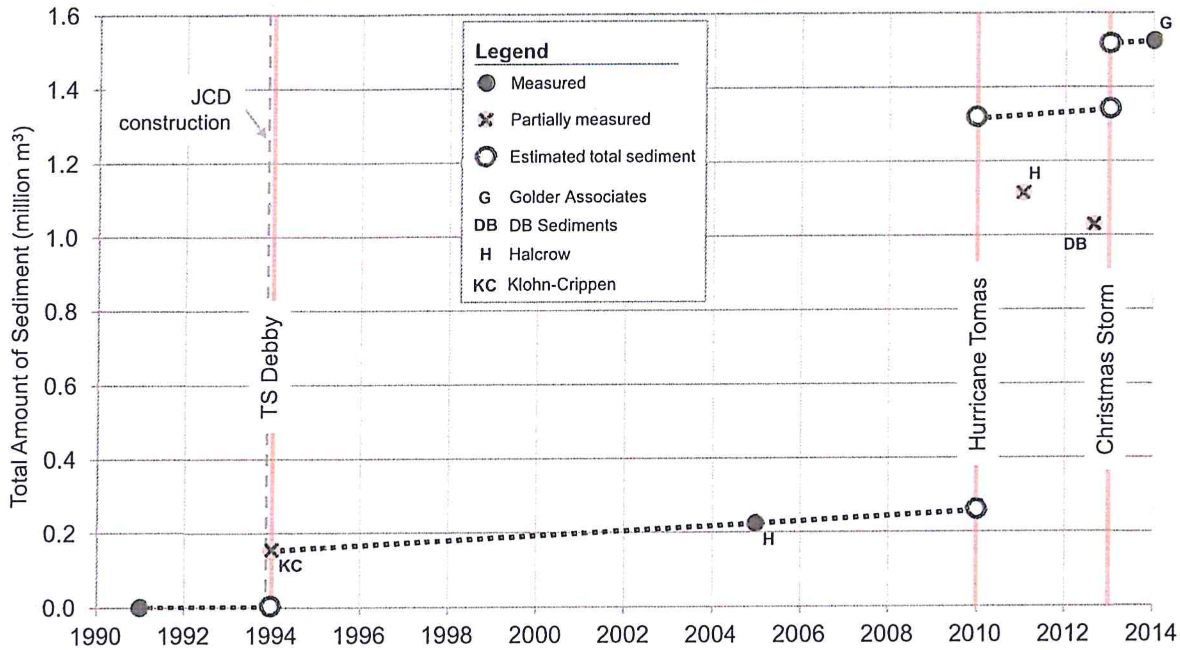
The estimated sediment yield for the Roseau Reservoir provides the basis for long-term sediment management. The sediment yield is expected to have two distinct components: a normal sediment load; plus a sediment load in years with extreme weather events. Some additional sediment is expected to be flushed over the spillway instead of settling in the reservoir. The estimated trapping efficiency of the reservoir is relatively high, about 85% (ranging from 75% to 90%) according to the method defined by Brune (1953). Therefore, an additional 15% of the natural sediment load along Roseau River is likely discharged over the spillway to the downstream Roseau River.

The normal sediment yield from low intensity erosion, not including large storm events, was estimated to be 5,700 $m^3$/year, based on interpretation of the 1995 and 2005 bathymetry surveys. This compares favourably with a calculated yield of 5,200 $m^3$/year (approximately 10,400 tonnes/year) using the empirically-based BQART method (Syvitski and Milliman, 2007) that was designed to capture geomorphic, geographic, geological features, plus human influences.

The sediment yield's second component is associated with large storm events that trigger new landslides and erosion of alluvial fans at existing landslides. One such landslide is indicated on Figure 9 where it has formed an alluvial fan along one side of the beach. Previous storms have delivered between 0.15 and 0.2 million $m^3$ to the reservoir and upstream beach. It was assumed that future tropical storms similar to Debby and the Christmas storm may generate up to 0.2 million $m^3$ of sediment, and that hurricanes such as Tomas may result in 1 million $m^3$ additional reservoir sediment.

The sediment yield from large storms depends on the expected frequency of these storms. A World Bank (2002) report assessed the probability of a tropical cyclone within the 220 km by 220 km grid square centred over Barbados (including Saint Lucia). The World Bank study estimated an 8% chance that a tropical storm will directly hit the island and a 5% chance for a hurricane similar to Hurricane Tomas. Therefore, the return period of a storm impacting Saint Lucia is about 10 to 15 years for a tropical storm and 20 years for a hurricane. It was assumed that every storm of these categories could deliver large volumes of sediment. The sediment yield component associated with extreme weather events was therefore estimated to be about 70,000 $m^3$ per year as a long-term annual average.

Together, the normal and extreme weather sediment yields result in an estimated long-term average sediment yield of 75,000 $m^3$ per year or about 9,500 tonnes/$km^2$/year captured by Roseau Reservoir. This is greater than the typical regional sediment yield of 500 to 2,100 tonnes/$km^2$/year, as calculated for various Caribbean islands by Larsen (1997).




Notes:
1. Halcrow (2005), Halcrow (2011), and DB Sediment (2013) only estimated sediment below 101.5 masl.
2. Sediment estimate from Klohn-Crippen (1994) was not directly measured but inferred by estimated landslide volumes.

*Figure 8: Reservoir Sediment Accumulation over Time*

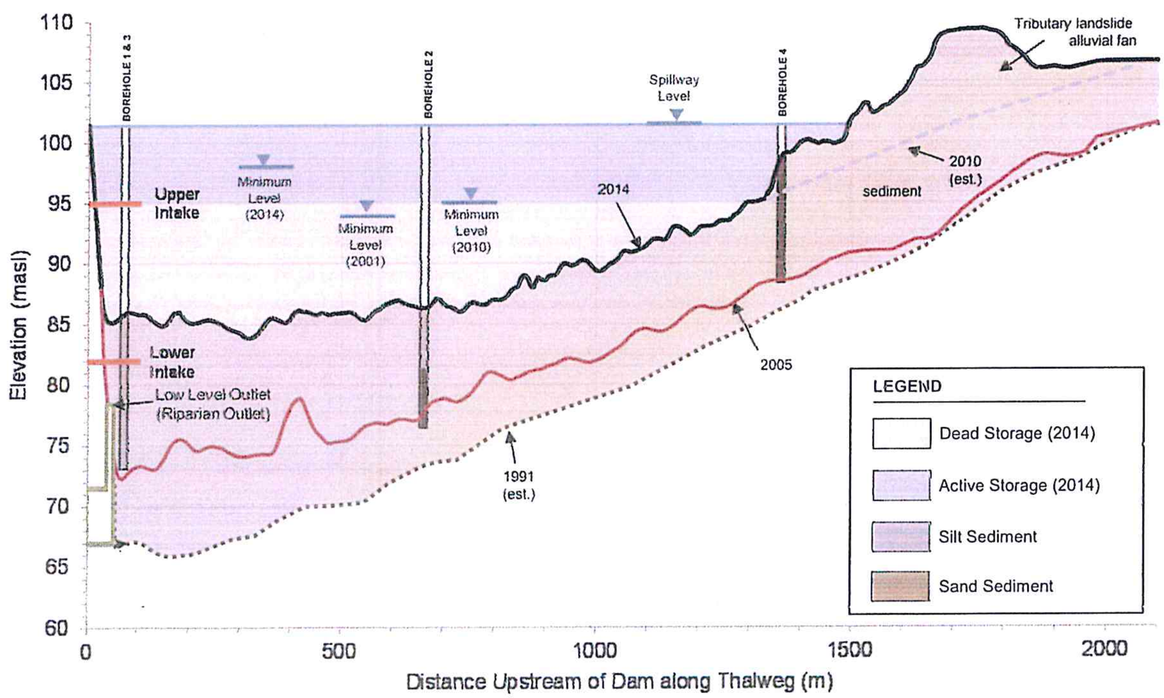



*Figure 9: Distribution of Reservoir Sediment (as measured along the Original Roseau River Thalweg)*

# 4.0 WATER SUPPLY ASSESSMENT

The following water supply assessment describes the amount of available water from the Roseau River at JCD, and the estimated reliability of water abstractions up to 10 IMGD. The reliability varies depending on the water supply, the timing of management decisions to implement water rationing, the active water storage capacity in Roseau Reservoir, on the availability of emergency water sources, and on the possible challenges resulting from future climate change. The assessment was based on water balance analysis using a simulation model developed specifically to support this study.

## 4.1 Water Balance Model

The water supply assessment is based on water balance analyses using a dynamic simulation model of the water supply system. It includes selectable water storage conditions due to sediment, customizable real-time operating rules to simulate the timing and rate of water rationing, emergency water sources, optional sources, alternate spillway invert elevations, and water use for a dredging operation. A schematic of the model components is shown on Figure 10.

The model was developed on the *iThink (Stella)* platform using 30 years of monthly historical data (1985-2014). The selected model parameters include recalculation of reservoir levels every 8 hours to maintain model stability and accuracy during periods of rapid changes. Model accuracy was verified using recorded reservoir levels. Simulation outputs are reported as monthly averages. The model is available for internal use by WASCO.

The model uses the following data as provided by WASCO:

- Reservoir storage: Reservoir Stage-Area-Storage curves were derived from design drawings and from available bathymetry. Storage curves were modified as required for different scenarios, such as sediment removal around the lower intake port or raising the dam.
- Watershed runoff: Monthly inflow to the reservoir was estimated from historical reservoir levels and abstraction rates from 2008 to 2014, accounting for net precipitation (i.e. evaporation loss), and further extrapolated based on precipitation records from 1985 to 2008 using an average runoff coefficient of 55% as derived from the available data.
- Precipitation: Monthly precipitation was based on the Millet rainfall gauge station. Missing data, at various times from 1985 to 1997 and near the end of 2010 post-Tomas, were estimated from a correlation of precipitation between Castries and Millet.
- Evaporation: Evaporation rates were conservatively based on Leonce (1978), assuming that lake evaporation may be as high as 1,750 mm per year. This conservative assumption may result in the calculation of slightly less watershed runoff, but does not affect the overall water balance accuracy.
- Spillway Information: Spillway is 33 m wide with an invert elevation of 101.5 m, based on the original design drawings. The spillway coefficient was assumed to be 1.45, similar to the Halcrow dam safety review recommendations (Halcrow, 2011).
- Intake information: The JCD intake elevations are 95 m and 82 m for the upper and lower intake ports, respectively. It was assumed that the intake capacity of each port is 10 IMGD, and that the capacity is gradually reduced to zero when the reservoir level is within 2 m of the intake port.

- Dam seepage: Seepage to the downstream Roseau River was estimated to be 70 L per minute, based on the Halcrow dam safety review (Halcrow, 2011).
- Water rationing rules: Management rules for water rationing were developed in part from historical water supply decisions by WASCO during previous drought conditions.
- Pipe leakage: The model does not account for leakage along the raw water pipelines, or as a result of losses along the treated water distribution system.

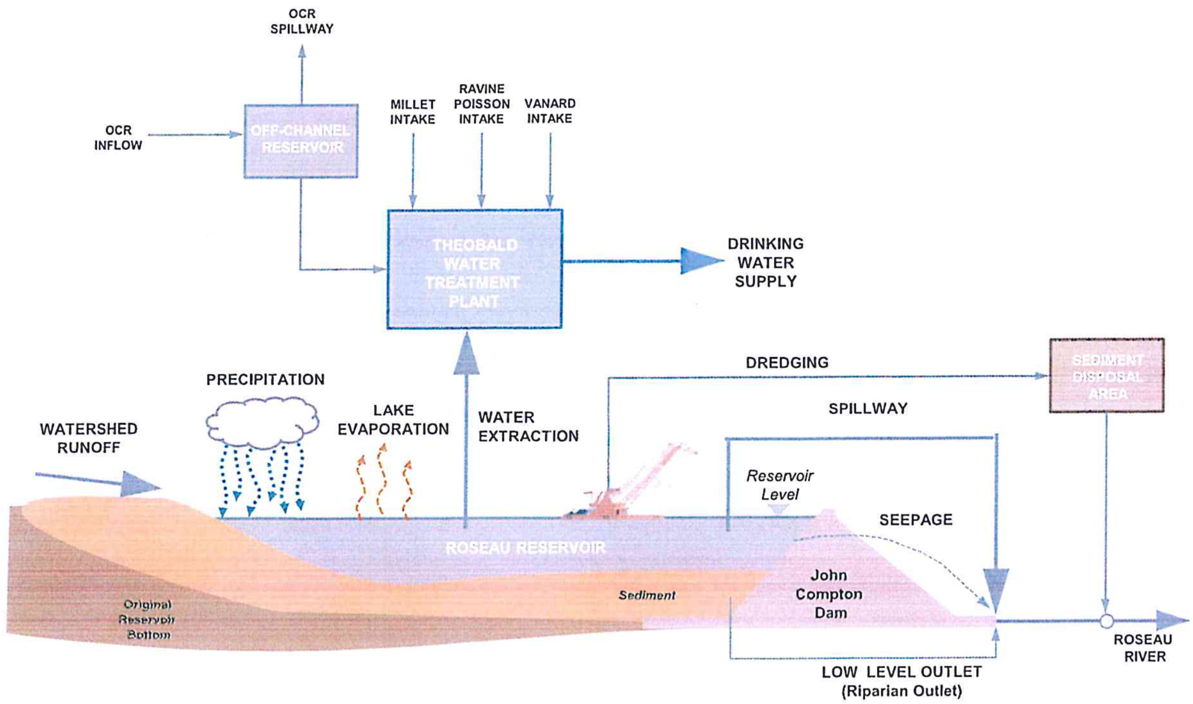



*Figure 10: Water Balance Model Components*

## 4.2 Historical Water Supply from JCD

Historical water abstractions at JCD ranged from 2.5 to 6 IMGD between 1996 and 2007, gradually increasing after the WTP was expanded in 2007 to a capacity of 10 IMGD. The current water demand from JCD is about 10 IMGD. Historical reservoir levels and abstraction rates are shown on Figure 11.

Drought conditions have resulted in low reservoir levels on several occasions. The lowest observed level was 94 m in August 2001. Other notable low levels occurred in 2007, 2010, and 2014. Although the lowest water level was observed in 2001, the water abstractions were significantly lower than today. The most dangerous drought condition occurred in 2014 when the lower intake port was not available, severely restricting the active storage capacity to water above the upper intake port at 95 m.

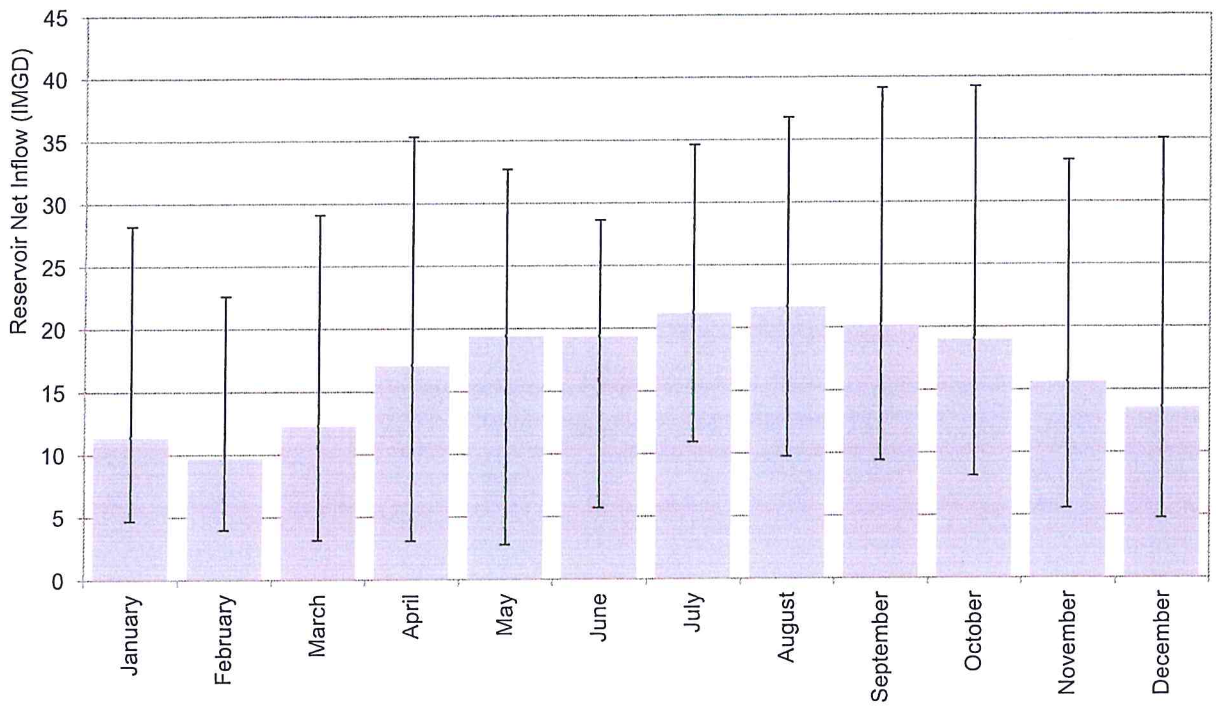



*Figure 12: Seasonal Reservoir Net Inflow (Average, Max, Min from 1985 to July 2014)*

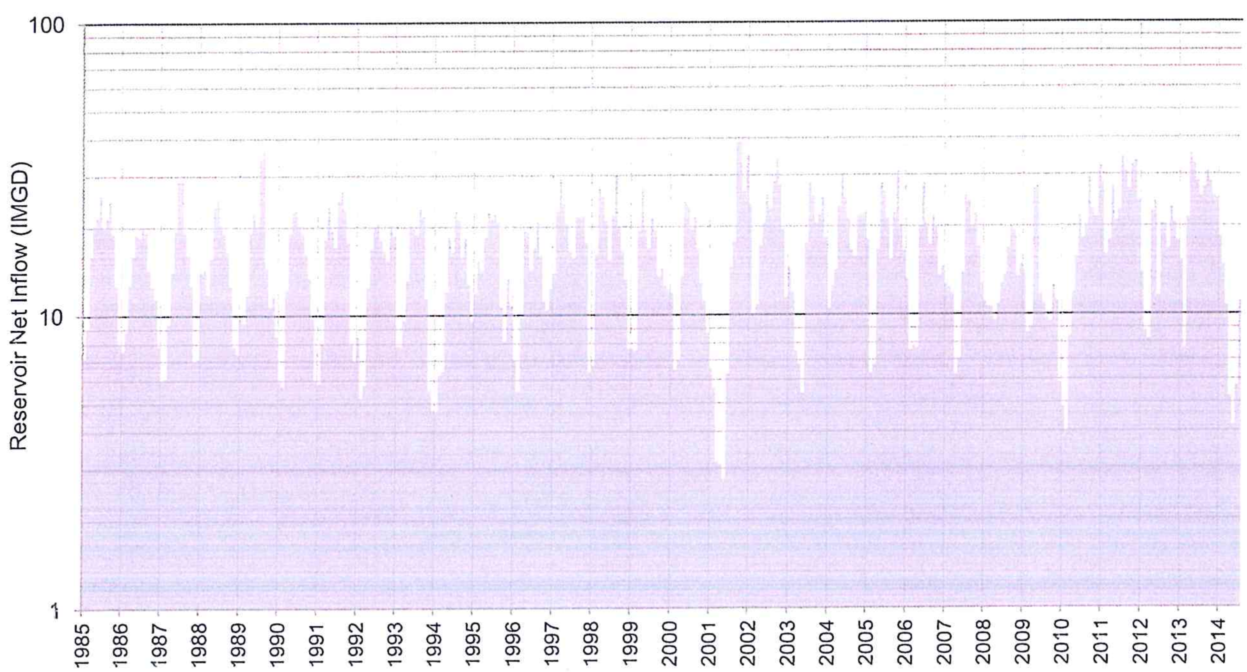



*Figure 13: Monthly Reservoir Net Inflow from 1985 to 2014*

## Droughts

Water availability was also assessed over a longer time period (1890 to 2014) to characterize the return frequency of severe droughts such as 2001. The assessment was based on an analysis of precipitation deficits or differences from the average conditions. This method eliminates the bias from large rainfall events within the wet season that may otherwise skew the total annual precipitation. The precipitation deficits were calculated from 1890 to 2014, extrapolating the historical record at Millet by using a monthly correlation between the Millet and Castries monitoring stations during a concurrent 17 year record.

The most severe recorded drought since 1890 occurred in 2001, as shown on Figure 14. This was due to 9 consecutive months of below normal precipitation. The drought of 2001 appears to be more severe than the drought of 2010 or 2014. The expected recurrence of recent droughts was estimated from frequency analysis of the precipitation deficits as:

- 2001 drought = approximately 100-year event; and
- 2010 and 2014 droughts = 10-year to 20-year return period events.

Overall, the recent period from 1985 to 2014 includes the 3 most severe droughts on record and 9 of the 10 most severe droughts. This period was selected as the basis for estimating near-future water availability at JCD, assuming that future climate may be similar to the recent frequent-drought period as compared to the earlier historical record. This assumption is expected to provide a suitably conservative basis for estimating water supply reliability.

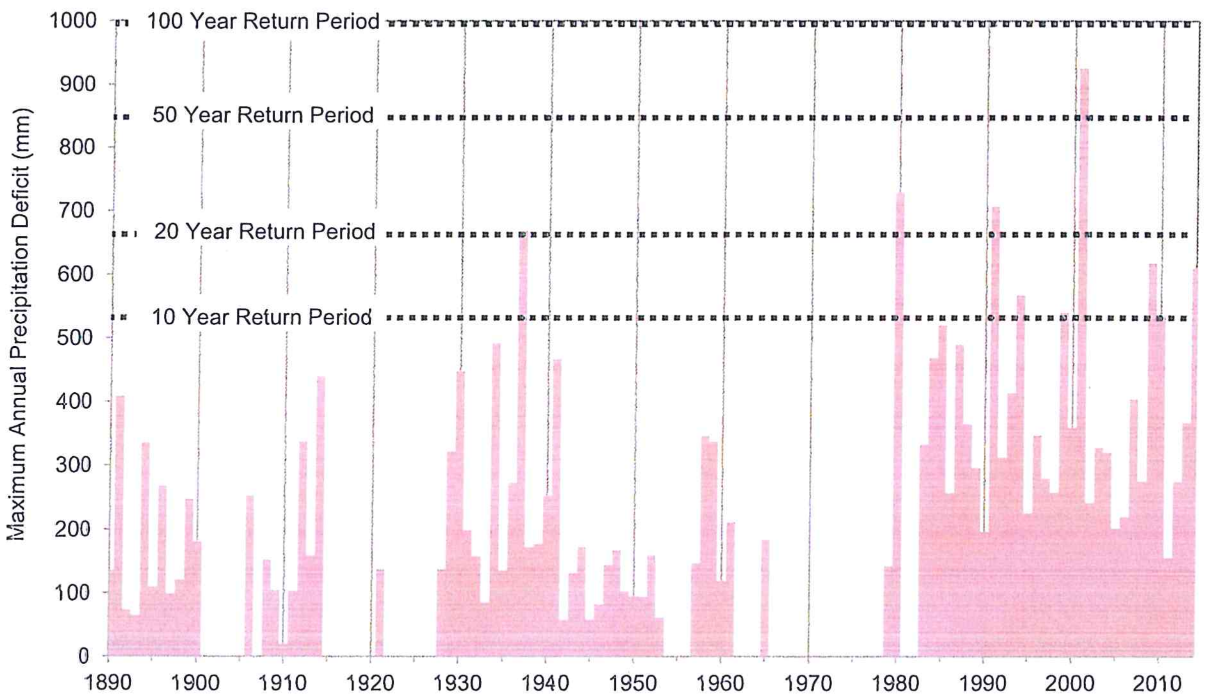



*Figure 14: Precipitation Deficit near Millet from 1890 to 2014*

## 4.4 Reservoir Storage Capacity

The Roseau Reservoir initially had a water storage capacity of 3.0 million $m^3$ and an active storage capacity of 2.7 million $m^3$ above the lower intake port. The storage capacity has been reduced over time due to sedimentation. Some of the sediment does not affect reservoir storage, because it has been deposited above the spillway elevation. Changes to the reservoir water storage over time are illustrated on Figure 15.

The current water storage in Roseau Reservoir is 1.9 million $m^3$ when the reservoir is full to the spillway elevation. However, the active storage available for water supply is only 1.1 million $m^3$ above the upper intake port, now that the lower intake port is blocked by sediment. The remaining active storage volume is equivalent to 30 days of water supply at 10 IMGD, assuming a minimum 2 IMGD inflow to the reservoir from the upstream Roseau River.

Sedimentation will eventually fill the reservoir and inundate the upper intake port. The remaining operating life of the reservoir will depend on the timing of future storms that deliver large volumes of sediment. The upper intake port will likely be inundated within the next 20 years with the current sediment yield of about 75,000 $m^3$ per year, assuming that half of the sediment is trapped along the beaches at the upstream end of the reservoir.

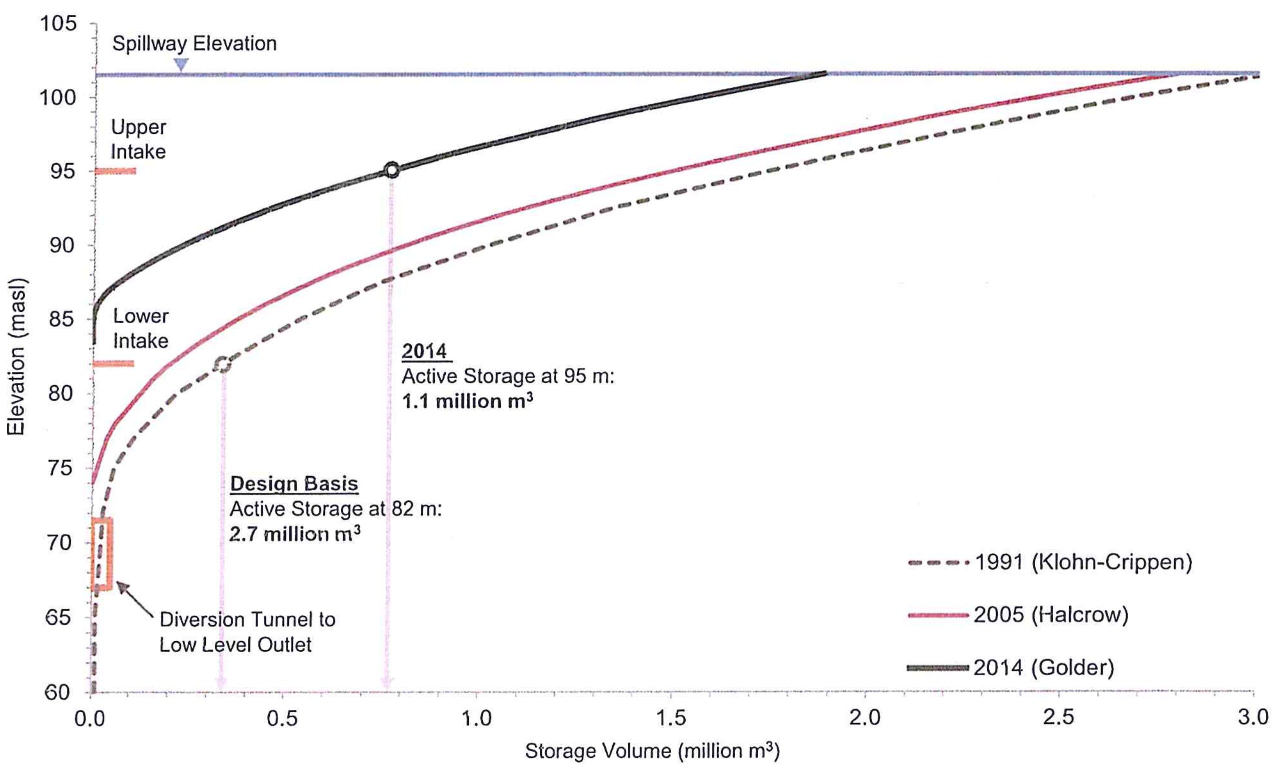



*Figure 15: Reservoir Stage-Storage Curves*

## 4.5 Water Supply Reliability

### Reliability Criteria

The water supply reliability is a measure of the percentage of years when the water supply can be maintained above a specified threshold. Emergency operations such as water rationing or a general inability to deliver water to customers would be considered failures. The following threshold reliability measures were approved by WASCO:

- Target supply: the target supply from JCD is close to 10 IMGD during normal operations;
- Normal supply: is when water abstractions at JCD are maintained at more than 80% of the target supply;
- Emergency water rationing: occurs when water abstractions at JCD must be temporarily reduced to between 60% and 80% of the target supply, as a result of low reservoir levels in the reservoir; and
- Water supply failure: occurs when water abstractions at JCD are forced to drop below 60% of the target supply when the reservoir is near empty, during which time it is assumed that WASCO cannot deliver sufficient water to meet the basic needs of its customers.

The target reliability was assumed to be >90% for rationing, and >95% against the possibility of a water supply failure. That is, rationing should be necessary less than once in ten years (on average), and that a water supply failure should occur less frequently than once in 20 years.

### Estimated Current Reliability

The estimated reliability for current operating conditions was calculated from water balance simulations assuming the continued use of WASCO's current triggers for water rationing, assuming that the lower intake port at JCD is not accessible due to sediment, and assuming that there are no emergency water sources available during drought conditions (although, in some years, WASCO has utilized emergency water sources at Vanard and Ravine Poisson intakes).

The water supply reliability is currently:

- Reliability (water rationing) = 37%, with rationing expected to be necessary 2 out of every 3 years; and
- Reliability (water supply failures) = 97%, with early rationing to avoid a water supply failure; resulting in non-failure for the equivalent of every historical year except for 2001, during which the abstraction rate would be reduced to about 3 IMGD.

The low reliability against water rationing is due in part to WASCO's current triggers for water rationing, which occur early in the dry season when the reservoir is starting to be drawn down. WASCO made this decision, for example, in 2014 because the lower intake port was not available. With only the upper intake port operable, rationing began when the reservoir level was about 2 m below the spillway elevation. When the lower intake was operable (pre-Tomas in 2010), rationing began when the reservoir level was 5.5 m below the spillway elevation.

The current operations are therefore expected to avoid a major water supply failure, but the high frequency of water rationing is the equivalent of reducing the available water from 10 IMGD to about 6 IMGD during the "dry" or drought season.

# 5.0 WATER MANAGEMENT OPTIONS

## 5.1 Introduction

The current operating conditions are not sustainable, because of reduced water storage in the Roseau Reservoir. WASCO has taken management measures to avoid a major water supply failure, but the measures result in frequent water rationing during the dry season when the water demand is relatively strong during the peak tourist season. Water rationing will likely be required in most years, effectively reducing the JCD water abstractions from 10 IMGD to about 6 IMGD. The reduced rate is necessary to avoid a more serious water supply failure as the reservoir is drawn down below the spillway elevation.

WASCO must further provide flexibility and resiliency to meet future challenges. In the future, the target water supply of 10 IMGD may need to be increased. Any management measures should be flexible to support this increase, where possible, or to support additional measures for increasing the supply. WASCO should also provide water supply system resiliency to manage shocks to the system, such as frequent storms, additional sedimentation, and climate change.

There are various water management options available to WASCO. These include "short-term" measures to improve the water supply reliability while continuing to rely on water abstractions at JCD. They also include "long-term" sediment management options, assuming that the JCD continues to be a viable water source. Alternative water sources are also considered. Finally, the selected water management measures will need to account for stakeholder interests in terms of environmental, social, and gender considerations. Several options are outside the scope of this study. They include: loss management along the water distribution system (e.g. repair of pipe leakage), and structural repairs to the existing dam.

## 5.2 Alternative Water Sources

There are several potential alternate water sources, but none of them are a viable near-term alternative to replace the water supply from JCD. Some sources could be considered by WASCO to augment water abstraction from JCD, and some sources could be considered following additional feasibility level investigations. Each potential water source is discussed below in terms of its potential to provide the target supply of 10 IMGD from JCD.

### Loss Management

WASCO currently has 56% non-revenue water (NRW), of which an estimated 53% is lost within the distribution system. The NRW is not uncommon among Caribbean countries, but still represents a significant volume of water that is supplied by JCD, processed at the WTP, and pumped into the distribution system. Water utilities often implement Loss Management plans to reduce the NRW. Any reduction of the losses within the distribution system will reduce the required water abstraction at JCD – effectively increasing the amount of available water. Examples of loss management include leak repairs, or pressure management to reduce leakage at night or within zones that have low demand. These kinds of plans are often resource-intensive long-term initiatives. It was assumed that WASCO will pursue this NRW "water source" separately from the reservoir de-silting plan.

### Water Conservation

Many water utilities have water conservation programs to help offset capital expenses associated with the development of additional water supply infrastructure. It is often a labour-intensive initiative with future results that are not reliable. This is a potential "water source" that may be pursued separately by WASCO.

## New Water Supply Dam

A new water supply dam along the Roseau River or within another valley may have the potential to replace the water supply from JCD:

- Along the Roseau River, the only available location for a new dam is between the existing JCD and the Millet River confluence. Operation of a new dam along the Roseau River likely utilizes the existing JCD as a sediment trap, and should therefore be considered as a replacement dam for JCD. The engineering feasibility of a dam along this reach is not known. However, the JCD design selected the current location for the dam so that rock could be sourced from downstream areas. A new dam would be located at or near the former borrow sources, potentially resulting in constructability issues and likely requiring new off-site borrow sources to be developed.
- Dam locations in other watersheds may be feasible, such as the Cul-de-Sac watershed or along the Troumassee River. Engineering feasibility studies are required prior to further consideration of a new dam.

## Small Intakes

Small river intakes are a potential alternate water source, similar to the Vanard or Ravine Poisson intakes. These sources often supply water during the wet season, but are unreliable during a drought. Ravine Poisson and Vanard are expected to have 0.1 IMGD water available at each station in the dry season during a dry year similar to 2014, based on available flow measurements in 2013 and 2014. The small river intakes could be of use during the wet season and in the dry season during non-drought conditions. However, the water quality from these intakes is expected to be relatively poor compared to JCD because the small river intakes typically have upstream human activities and associated contaminants, whereas JCD has a pristine undeveloped watershed.

## Groundwater Wells

It was assumed that groundwater is likely not a viable source for supplying 10 IMGD. Groundwater investigations in the 1960's indicated good reserves of water, but these reserves have never been exploited due to water quality problems associated with hardness, salinity and iron content (GOSL, 2001; Flyn et al. 1998). Flynn et al. (1998) found that groundwater sources are generally limited to the alluvial plains (e.g. Roseau and Cul-De-Sac) rather than the interior of the island, which is underlain predominantly by volcanic bedrock (i.e. low permeability rocks). A more recent geophysical study may indicate the potential for groundwater resources in the lower Roseau valley near Jackmel (pers. comm. WASCO), but this resource has not been proven in terms of the sustainable supply.

## Rainwater Harvesting

Rainwater harvesting is a feasible alternative water source that is increasingly used in both developing and developed countries. It requires standards for use and for construction. Any new construction could consider rainwater harvesting for grey water uses. This alternative water source is a long-term option for Saint Lucia. It is expected to be feasible due to the annual rainfall across the island which ranges from 1,450 mm near the coast and 3,450 mm in the mountainous regions. However, rainfall harvesting is not expected to provide short-term relief because it typically requires significant investment to construct storage tanks and to convert buildings to dual plumbing.

### Import Water

Water can be imported from other countries, such as Dominica. Dominica has offered water for import to Saint Lucia (pers. comm. WASCO), whereby WASCO would need to develop infrastructure for capturing, transporting, and treating the water. Feasibility studies have not been completed.

### Desalination

Freshwater can be manufactured from sea water at a cost of perhaps $100,000US per day for 10 MGD ($10US per 1,000 gallons). Various cities around the world have developed desalination plants. Desalination is generally energy intensive, which is a limiting factor in Saint Lucia where energy resources rely on relatively expensive diesel fuel. This water source was assumed to be too expensive compared to the current surface water supply at JCD, but may need to be considered in the future.

### Limits on Development

An equivalent water source is to limit the amount of development on Saint Lucia. This would be a political decision.

## 5.3 Options to Improve Water Supply Reliability

### 5.3.1 Overview

Several measures were considered for improving the water supply reliability at JCD. These options do not address the long-term implications of continued sediment delivery to Roseau Reservoir. The estimated sediment yield to the reservoir and expected lifespan of the reservoir confirms that additional long-term sediment management measures are needed. Therefore, the measures described below will need to be considered in conjunction with a long-term sediment management plan.

The water supply reliability measures that were considered are:

- Increase the active storage capacity of Roseau Reservoir by:
  - Removing reservoir sediment near the lower intake port;
  - Removing all of the reservoir sediment; or by
  - Installing a temporary intake at 88.5 m to utilize water storage below the upper intake port.
- Develop emergency water sources, such as:
  - Vanard intake along the Roseau River downstream of JCD;
  - Ravine Poisson intake; plus the
  - Cul-de-Sac off-channel reservoir (OCR) near Deglos.
- Increase the reservoir storage by:
  - Modifying the existing spillway;
  - Raising the existing dam;
  - Constructing a second dam along Roseau River downstream of JCD, and

- Storing additional water at an off-site location.

- Modify the drought management rules for triggering water rationing.

These options are described below, with corresponding model results for the calculated water supply reliability summarized in Table 2, Table 3, and Table 4.

### 5.3.2 Remove Reservoir Sediment near the Lower Intake Port

The lower intake port is currently inoperable due to 4 m of sediment accumulation above the intake. This condition resulted in a loss of about 0.8 million $m^3$ of "active" water storage, because water below the upper intake port is not accessible for water supply. The remaining active storage volume is only 1.1 million $m^3$, compared to the original 2.7 $Mm^3$ (the original dead storage volume was 0.3 million $m^3$).

Removing the sediment in the immediate vicinity of the lower intake port would increase the active storage, and result in an equivalent improvement to water supply reliability by reducing the need for water rationing. Reliability, in terms of avoiding periods of water rationing, would increase from 37% to 63% (i.e. rationing once in three years on average). The existing water rationing rules would continue to protect against a water supply failure during drought conditions, except for a severe drought such as 2001. The reliability against a water supply failure would continue to be 97% (i.e. a failure occurring once in 30 years, on average). Results are summarized in Table 2.

### 5.3.3 Remove All Reservoir Sediment

Similarly, removing all of the reservoir sediment does not result in a significant marginal benefit compared to removing the sediment near the lower intake port. The water supply reliability would be improved from 63% to 77%. Results are summarized in Table 2.

### 5.3.4 Install a temporary intake

A temporary intake would achieve a similar improvement in reliability compared to removing sediment near the lower intake port. The installation of a temporary intake may be possible in the event that sediment removal is delayed. However, a temporary intake would eventually be covered with sediment.

### 5.3.5 Vanard and Ravine Poisson Emergency Water Sources

The use of small river intakes on an emergency basis may offset some water abstraction at JCD. The available existing intakes are Vanard (Roseau River), and Ravine Poisson intakes. These intakes have been developed as temporary structures and will require additional effort to be utilized on a regular albeit emergency basis. The available water at each intake is limited, and is generally expected to decrease as drought conditions persist. Some stream flow information is available to provide a basis for emergency use, as shown on Figure 16, which indicates at least one measurement of about 0.1 IMGD. Based on this information, the intakes are each expected to produce up to 0.5 IMGD near the beginning of the dry season, but gradually reduce to about 0.1 IMGD.

Vanard and Ravine Poisson intakes are expected to help improve the overall water supply reliability if they are utilized early in the drought. Early utilization of the intakes as the reservoir is drawn down, similar to the rule shown on Figure 17, is expected to result in a modest increase in reliability against water rationing from 37% to 50%. In combination with daylighting the lower intake port, the reliability would increase to 80% (i.e. water rationing required once every 5 years on average). The results for various scenarios using the river intakes as emergency water sources are summarized in Table 2.

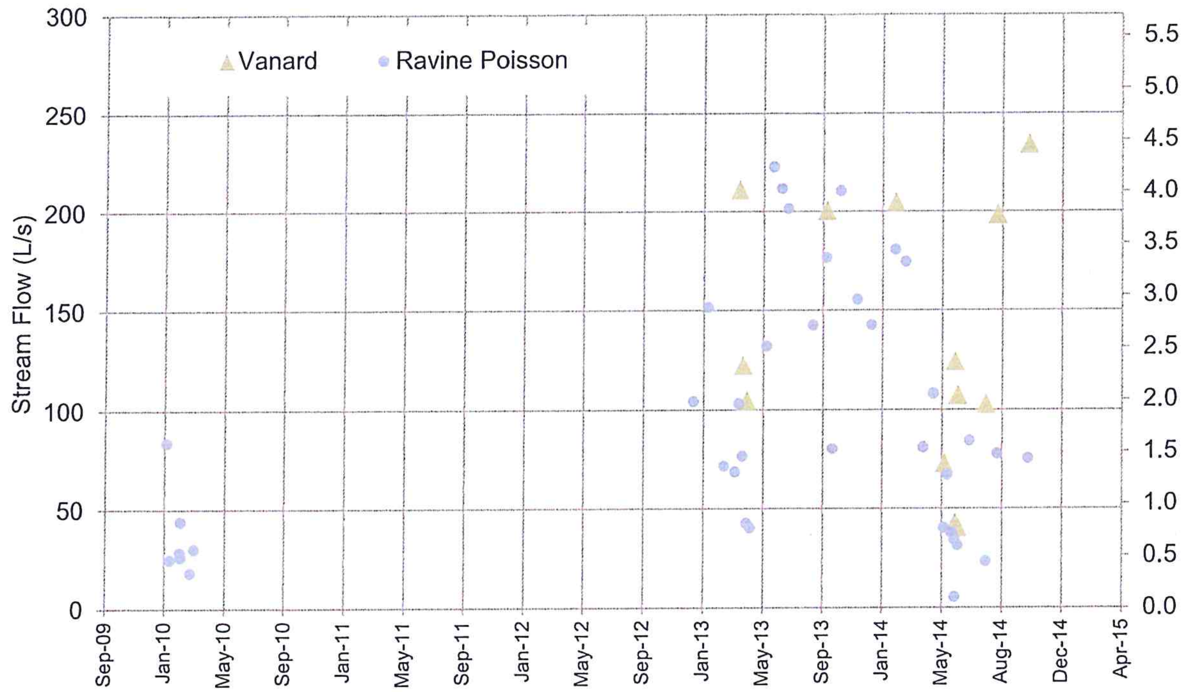
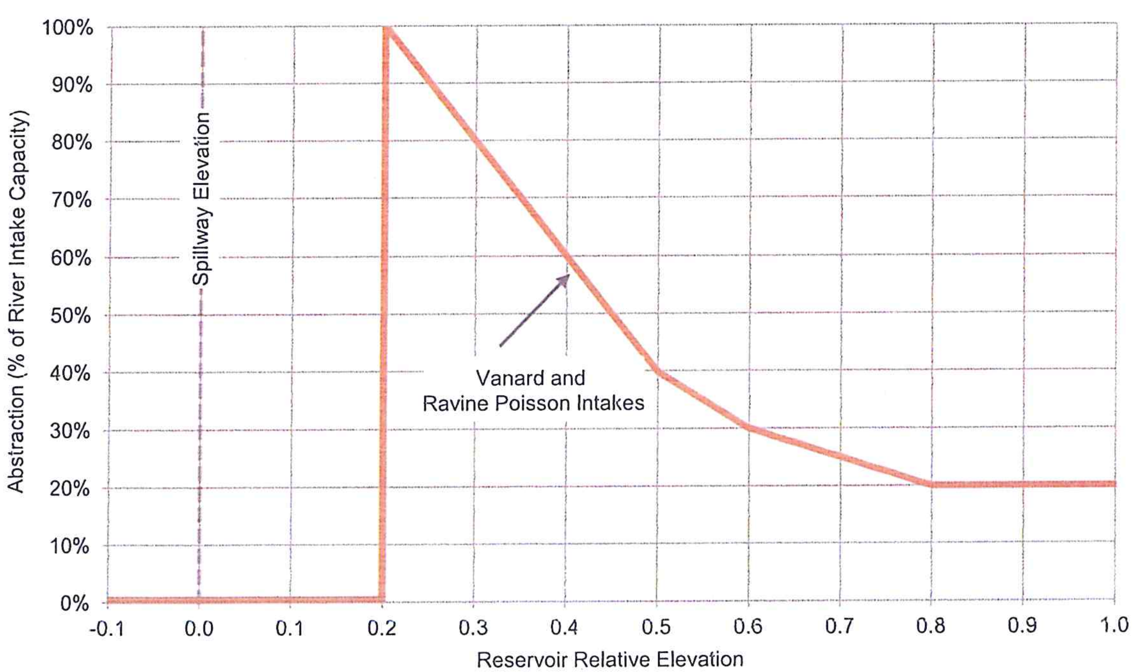



*Figure 16: Available Low Flow Records for Ravine Poisson and Vanard Intakes (not including flood flows)*




Note: Relative elevations are between the spillway elevation (0) and the lowest available intake port (1). River water intake capacity at Vanard and Ravine Poisson is approximately 1 IMGD.

*Figure 17: Drought Rule for Triggering the Use of Emergency River Intakes (Vanard and Ravine Poisson)*

### 5.3.6 Cul-de-Sac Off-Channel Reservoir Emergency Water Source

The Cul-de-Sac off-channel reservoir (OCR) was constructed near Deglos in 2002 for agricultural irrigation purposes. It is currently unused and could be available as an emergency water source. The storage capacity is 12.3 million (imperial) gallons and the reservoir is filled naturally by an uphill spring, at an assumed rate of 0.1 IMGD (7 L/s) during the dry season (based on a single measurement of 20 L/s in December 2014). The spring would therefore naturally re-fill the reservoir in about 3 months or less.

The most likely scenario for utilizing the OCR during an emergency is to treat and distribute water locally from the reservoir facility, either by truck or as a standpipe for customers. It was assumed that the OCR would be used as a last resort during a prolonged drought, because the OCR capacity is the equivalent of less than 2 days water supply. During an emergency, the OCR would be drained completely in about 12 days at a rate of 1.5 IMGD. Development of the OCR as an emergency water source will require rehabilitation of the existing spillway, replacement of the pond liner, and a portable water treatment unit for emergency use.

The OCR would not improve the water supply reliability, and the OCR would not help to avoid a water shortage during a drought similar to 2001. The relative value of the OCR is in reducing the maximum severity of the water shortage. The relative difference may have benefits for the distribution of the remaining supply, to be confirmed by WASCO. The OCR would likely be utilized about once every 10 years if it is implemented with other emergency water sources and sediment management measures. The expected OCR water supply benefits are summarized in Table 2.

It may be feasible to increase the OCR storage capacity by raising the containment berms and installing a new spillway. Raising the berms by 3 m would increase the storage capacity to about 24.6 million (imperial) gallons. This increased storage does not improve the water supply reliability, but further helps to reduce the severity of a water supply failure. The relative value of increasing the OCR storage capacity is summarized in Table 3.

### 5.3.7 Modify the Spillway

Previous reports have recommended that the JCD spillway should be increased by 3 m to provide sufficient water storage during an extended drought. These options are not recommended because the reservoir will still eventually fill with sediment, and because these measures may cause both dam safety issues and unnecessary downstream flooding.

The spillway cannot be raised on a permanent basis due to dam safety considerations. A raised spillway would reduce the flow capacity, and therefore would put the dam at risk of failure during floods that are much smaller than the design flood. The spillway, therefore, can only be raised on a seasonal or temporary basis or as part of a dam raise.

Temporary spillway structures such as a Fuse Gate would raise the spillway level but would be designed to fail in a large flood event. They are an engineering solution to protect infrastructure by quickly releasing a lot of water. They therefore cause much larger downstream floods because the release is delayed and then compressed into a much shorter time frame in the form of a massive flood wave. This can work in cases where there is no downstream infrastructure that may be impacted by larger-than-natural floods. However, the JCD is upstream of many private properties that would likely be damaged by larger-than-natural floods.

Seasonal spillway structures, such as an Obermeyer Weir, would allow the spillway to be raised and lowered as needed. Halcrow recently recommended this solution to raise the spillway 3 m. This engineering solution relies on a selected date to raise and then to lower the weir. The gate would be raised prior to the drought (dry) season in November and then lowered at the beginning of the storm (wet) season in June. The gate would provide additional storage if the reservoir filled after the gate is raised in November.

The Obermeyer Gate requires careful timing to avoid any large storms at the end of the wet season, while also raising the gate in time to fill the reservoir to the top of the Obermeyer Gate before the reservoir is drawn down during the dry season. The logistics of making these timely decisions are challenging, and effective use of the gate is likely not possible. Specifically, the challenges of implementing an Obermeyer Gate are:

- If the gate is raised too late, the reservoir may not fill prior to a dry season drought. The 1994 drought, for example, would have started to draw down the reservoir at the end of October. In that case, raising the spillway in November or December would provide no additional storage.
- If the gate is raised too early and must be suddenly lowered to accommodate a storm, the sudden release of an additional 3 m of water would most likely increase the natural flood peak. The 2013 Christmas Trough, for example, would have resulted in additional downstream flooding, or worse if WASCO staff did not have time to lower the gate ahead of the storm.
- Failure to lower the gate prior to a large storm may result in overtopping of the dam and potential dam breach. WASCO staff may not be able to lower the gate if on-site staff are evacuated similar to Tomas, or if access roads become impassable.
- If the gate is raised to early and suddenly lowered to accommodate a storm that is forecasted but does not materialize (or is not as severe as forecasted), then the downstream flooding caused by lowering the gate would have been unnecessary.

### 5.3.8 Raise the Dam

We understand that the reservoir was designed to provide a sufficient water supply to meet WASCO's needs up to 2025. By that time, it may be necessary to have constructed new storage dam or substantially increase the capacity of the reservoir. Additional water storage at JCD could improve the water supply reliability or allow water abstractions to increase above 10 IMGD.

While the dam was not designed to be raised, it appears to be feasible to raise the dam by as much as 10 m by placing additional rock fill on the downstream face to raise the crest of the dam. A new overflow chute spillway would need to be constructed on the right abutment. It is unlikely that the existing spillway could be used with the raised dam as it would have to remain in operation during construction of the dam raise and there would be insufficient time between wet seasons to raise the rock fill in the spillway section and reconstruct the spillway in the current location at a higher level.

Raising the dam would also provide an opportunity to resolve dam safety issues associated with an undersized spillway, by constructing a new spillway with sufficient capacity to pass the design flood. The existing spillway is not sufficient to pass the original design flood, according to the Halcrow (2011) dam safety report. Golder supports Halcrow's dam safety conclusions as reasonable.

If the dam and spillway are raised by about 10 m, the sustainable water supply limit for JCD would increase to 12 IMGD. Further water abstractions above 12 IMGD would erode the water supply reliability below the target 95%. The effect of raising the dam is documented in Table 4. The various scenarios in Table 4 assume that the Vanard and Ravine Poisson emergency water sources are also used.

The expected consequences of raising the dam and abstracting additional water are:

- Increased flooded area upstream of the dam;
- Reduced frequency of spills over the spillway;
- Reduced downstream flow along Roseau River; and
- Disturbance of new borrow areas for rock sourcing.

It may be possible to construct a second dam along the Roseau River within the narrow valley between JCD and Millet. It was assumed that this option, if proven feasible from a constructability perspective, would be the equivalent of replacing the existing JCD. This is a long-term option that has not been proven and is recommended to be further investigated through a subsequent study.

### 5.3.9 Store Additional Water at an Off-site Location

The water supply reliability may be improved if sufficient additional water can be stored at an off-site location. The existing water abstraction target of 10 IMGD at JCD would require about 2 million $m^3$ additional water storage to make-up for the existing supply limit of 6 IMGD during a drought. It is more likely that off-site water storage would be considered for increasing the water supply from JCD from 10 IMGD to 11 IMGD.

The only viable location for storing a large volume of water at an off-channel location is along the lower Roseau River valley near Jackmel. The overall concept is illustrated on Figure 18. This location is about 8 km from JCD via pipeline, plus a further 4 km pipeline to the water treatment plant. A relatively large 2 m diameter pipe would be required to transport a large volume of water over a short duration from JCD. The pipeline would likely have a 10 m diameter drop inlet (or equivalent) installed within the reservoir near the boat launch. Water storage would be provided by a containment berm in the valley bottom, where a cut and fill balance would be used to create the required berms. Existing agricultural land would be cleared, and up to 300,000 $m^3$ of unsuitable fill material will need to be transported to an approved off-site disposal area (depending on the final site selection and design details). The property size will need to be between 50 ha and 100 ha, depending on the amount of water to be stored. The infrastructure costs for two pipelines plus the earthworks and ancillary works are expected to be relatively high compared to other options at JCD.

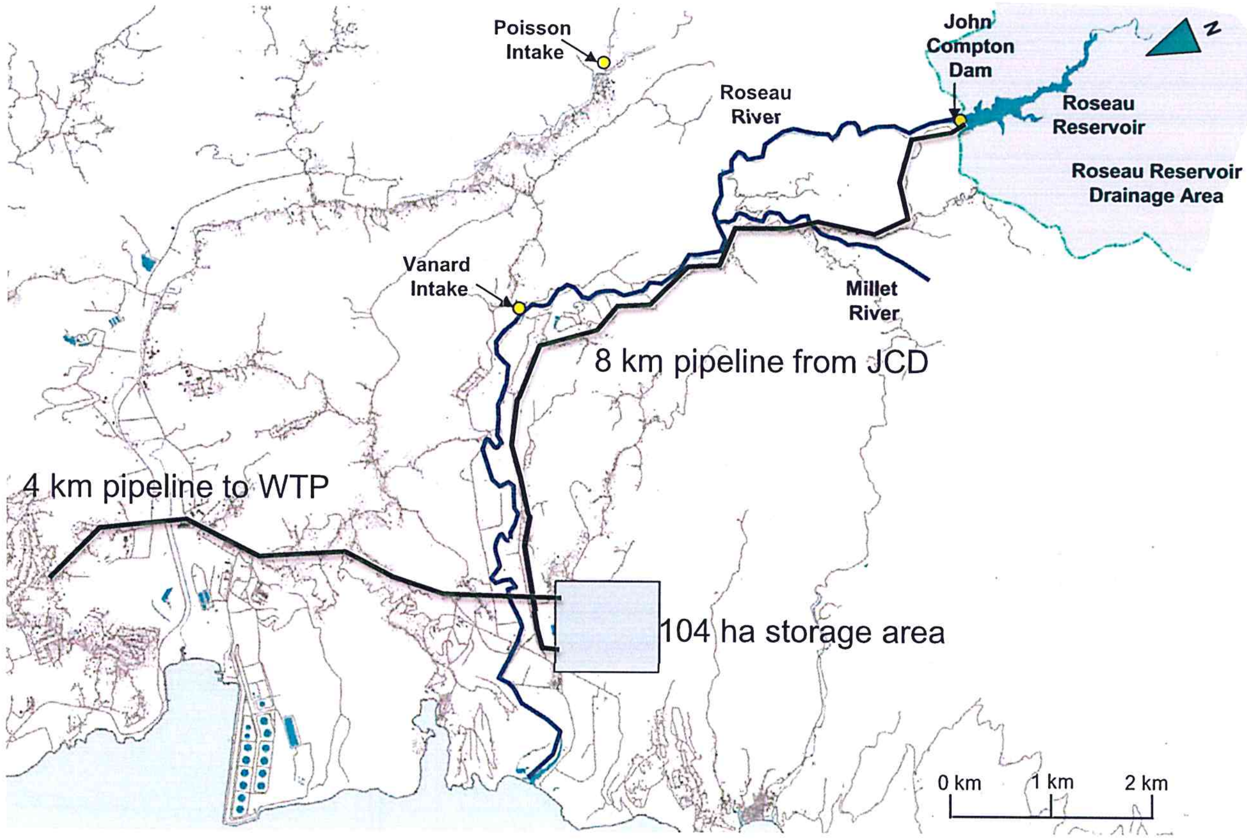
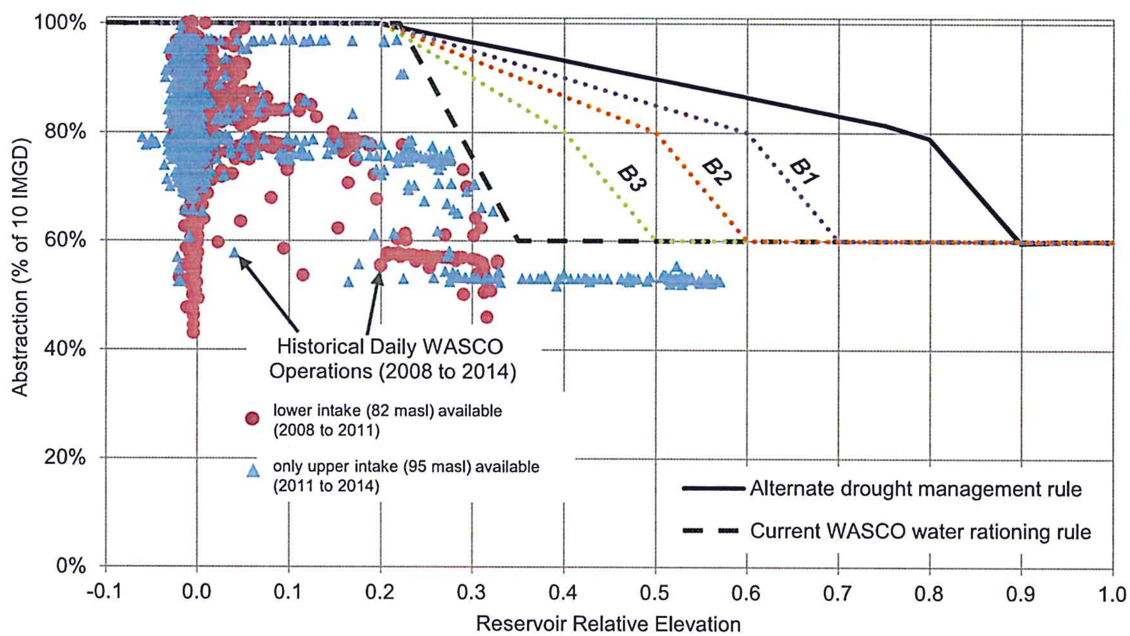



*Figure 18: General Layout of Off-site Water Storage near Jackmel*

## 5.3.10 Modify the Triggers for Water Rationing

WASCO has existing rules for water abstraction at JCD during drought conditions. The rules are focused on preventing a water supply failure by water rationing as the reservoir is drawn down. Based on historical operations, WASCO will likely implement water rationing in most years until the sediment around the lower intake port is removed. This is the equivalent of supplying less water during the dry season when the water demand from tourism is strongest. The cost of this approach is a reliability of only 37%, equivalent to water rationing 2 of every 3 years.

Alternative rules for triggering water rationing may be used to reduce the frequency of water rationing in combination with other options. The existing rules to trigger early water rationing would have a reliability of 63% after the lower intake port is available, or after a temporary water intake is installed. This is equivalent to rationing about once every 3 years. The alternate drought management rule shown on Figure 19 would further avoid water rationing without causing additional water supply failures. Reliability could be improved to 87%, equivalent to rationing about once every 8 years. The analysis results for several scenarios are summarized in Table 3.




Note: Elevations are relative to the spillway elevation (0) and the lowest available intake port (1).

*Figure 19: JCD Water Abstraction Rules based on Reservoir Levels*

**Table 2: Water Supply Reliability for Various Options**

| **Emergency water sources[a]** | | No emergency sources | | | Vanard, Ravine Poisson, OCR | | |
|---|---|---|---|---|---|---|---|
| **Reservoir sediment removed** | | None[b] | Around Intake[c] | All Sediment[d] | None[b] | Around Intake[c] | All Sediment[d] |
| **Historical drought rule** | Reliability (rationing) | **37%** | **63%** | 77% | 50% | 80% | 83% |
| | Reliability (supply failure) | **97%** | 97% | 97% | 97% | 97% | 100% |
| **Alternate drought rule[e]** | Reliability (rationing) | 63% | **87%** | 93% | 77% | **90%** | 97% |
| | Reliability (supply failure) | 73% | 97% | 97% | 83% | **97%** | 97% |

Notes:

[a] Emergency water sources include Vanard and Ravine Poisson (capacity of 0.5 IMGD in wet season, 0.2 IMGD in dry season) and the Emergency 12.3 IMG OCR (1.5 IMGD)

[b] 'None' scenario assumes that the lower intake port is not accessible and that no sediment is removed (do nothing scenario).

[c] 'Around Intake' scenario assumes that the lower intake port is accessible and no other sediment is removed.

[d] 'All Sediment' scenario assumes the 1995 storage curve, prior to any sediment accumulation within the reservoir.

[e] 'Alternate drought rule' refers to delayed triggering of water rationing compared to current WASCO practice.

**Table 3: Sensitivity of Water Supply Reliability to Cul-de-Sac Reservoir Size**

| OCR Size (IMG) | Water Reliability Parameter | Historical Drought Rule | B-3 Rule | B-2 Rule | B-1 Rule | Alternate Drought Rule |
|---|---|---|---|---|---|---|
| 12.3 existing capacity | Reliability (rationing) | 83% | 90% | 90% | 93% | 97% |
| | Reliability (failures) | 100% | 97% | 97% | 97% | 97% |
| | Minimum water supply (IMGD) | 6.0 | 5.1 | 4.9 | 4.5 | 3.7 |
| 24.6 potential capacity after improvements | Reliability (rationing) | 83% | 90% | 90% | 93% | 97% |
| | Reliability (failures) | 100% | 97% | 97% | 97% | 97% |
| | Minimum water supply (IMGD) | 6.0 | 5.7 | 5.0 | 4.7 | 4.2 |

Notes:

Based on 10 IMGD water supply from JCD, removal of all sediment within the reservoir, and including the use of emergency water sources (Vanard, Ravine Poisson, and the Cul-de-Sac Off-Channel Reservoir).

**Table 4: Sensitivity of Water Supply Reliability to Dam Raise Scenarios**

| Reliability (No Rationing) | JCD Water Abstraction (IMGD) | | | | | |
|---|---|---|---|---|---|---|
| **Dam Raise Scenario** | 8 | 9 | 10 | 11 | 12 | 13 |
| 10 m | 100% | 100% | 97% | 97% | 93% | 87% |
| 8 m | 100% | 100% | 97% | 97% | 90% | 83% |
| 6 m | 100% | 100% | 97% | 93% | 87% | 80% |
| 4 m | 100% | 97% | 97% | 93% | 83% | 77% |
| 3 m | 100% | 97% | 97% | 90% | 83% | 73% |
| 2 m | 100% | 97% | 97% | 87% | 77% | 70% |
| No Dam Raise | 97% | 97% | 90% | 77% | 77% | 50% |

| Reliability (No Failures) | JCD Water Abstraction (IMGD) | | | | | |
|---|---|---|---|---|---|---|
| **Dam Raise Scenario** | 8 | 9 | 10 | 11 | 12 | 13 |
| 10 m | 100% | 100% | 100% | 97% | 97% | 93% |
| 8 m | 100% | 100% | 100% | 97% | 97% | 90% |
| 6 m | 100% | 100% | 97% | 97% | 93% | 87% |
| 4 m | 100% | 100% | 97% | 97% | 93% | 83% |
| 3 m | 100% | 100% | 97% | 97% | 93% | 83% |
| 2 m | 100% | 97% | 97% | 97% | 87% | 80% |
| No Dam Raise | 100% | 97% | 97% | 97% | 80% | 77% |

Notes: The dam raise scenarios assume that the lower intake port is available, emergency water sources are used, and the alternate drought rule is used.

### 5.3.11 Recommended Combination of Water Supply Reliability Options

The options to increase water supply reliability range from increasing the active storage capacity, developing emergency water sources, to modifying the rules for triggering water rationing. Many of these options, in isolation, have a relatively small marginal impact on water supply reliability. However, combinations of measures may have a strong collective basis for reducing the frequency of water rationing.

There is a combination of measures that is expected to improve the water supply reliability from 37% to 90%, to the equivalent of water rationing once every 10 years. Similarly, a significant water shortage or water supply failure would have an acceptably small probability equivalent to once every 30 years on average. The estimated water supply reliability from JCD assumes that the current climate trend continues to result in frequent droughts.

The preferred combination of water supply reliability options has the following marginal benefit, in order of relative benefit:

- Increasing the active storage by removing sediment around the lower intake improves water supply reliability from 37% to 63%. Removing all of the sediment would result in a further improvement to 77%, but this is a theoretical limit that will not occur because of additional sediment delivered to the reservoir each year.
- Adjusting the drought management rules to delay water rationing will further improve the reliability from 63% to 87% after reinstating the lower intake port.
- The addition of emergency water sources such as the Vanard and Ravine Poisson intakes further improves reliability from 87% to 90%.
- The addition of the Cul-de-Sac OCR would further reduce the severity of a water supply failure.
- There is no benefit to expanding the OCR, in terms of water supply reliability.

Raising the dam by up to 10 m will help WASCO to expand the water supply to 12 IMGD, subject to implementing additional measures for managing reservoir sediment.

## 5.4 Sediment Management Options

### 5.4.1 Overview

Sediment is expected to further accumulate in the Roseau Reservoir. A long-term sediment management plan will be needed to maintain the reservoir capacity for water supply purposes. A number of sediment management strategies exist. They can be applied either individually or in some combination. The overall concepts are: to reduce the amount of sediment captured by the reservoir; to create conditions that will prevent (or at least to minimize) the deposition of sediment; or to remove whatever sediment has been deposited in the reservoir. Potential downstream considerations include river morphology, nutrient supply, and aquatic habitat.

The sediment management methods described in the following sections have been grouped as follows:

- <u>Upstream catchment sediment management</u> measures are expected to result in a relatively small improvement over the existing conditions and will not recover the storage capacity that has already been lost to sediment accumulation.
- <u>Reservoir sediment routing</u> measures are not possible in the case of JCD, because they would require a flow diversion to route the water and new sediment around the reservoir. This is not possible because there is a relatively small amount of surplus water after abstractions for water supply, which require more than 50% of the flow during an average year. And it would be technically challenging to create a diversion given the current configuration of the dam and steep valley walls.

- Sediment removal measures are the only realistic means of long-term sediment management at JCD, although some of these methods are not feasible or are not desirable. Dredging is the preferred sediment removal method.
- Sediment transport options include trucking, piping, and river transportation.
- Sediment disposal options include a variety of nearby locations, private land locations near Jackmel, and offshore locations.

The options for long-term sediment management can generally be categorized as a combination of three activities: removal of the sediment, transportation of the sediment, and final disposal. A "map" of the options is shown on Figure 20. Altogether, there are a large number of possible combinations. Many of these combinations, however, are fatally flawed or economically expensive with relatively undesirable environmental/social impacts.

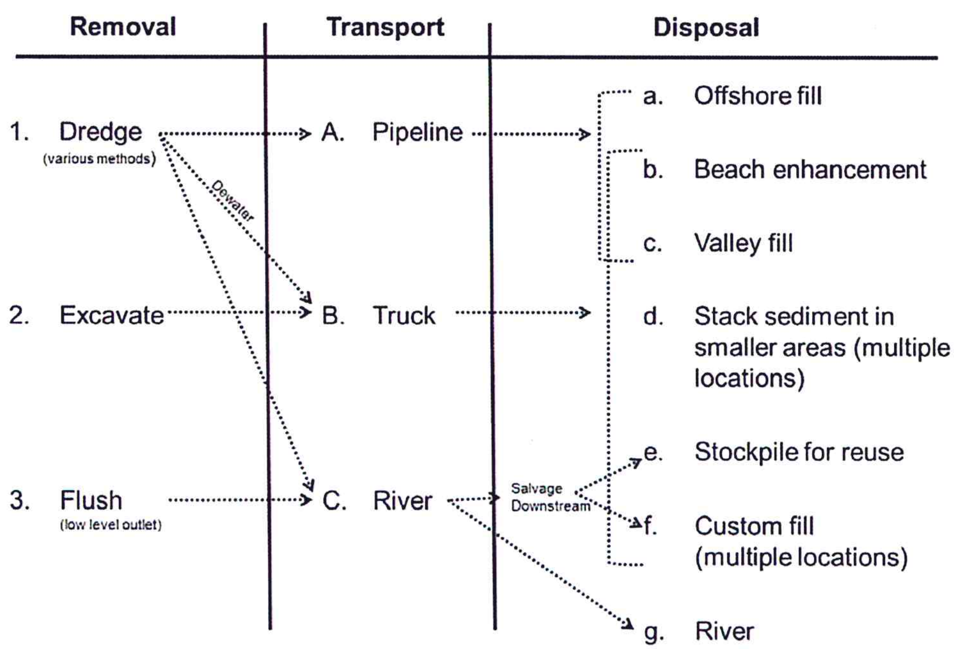



*Figure 20: Map of De-Silting Options*

### 5.4.2 Upstream Catchment Sediment Management Options

The principal methods to reduce sediment yield from catchments are re-vegetation, contour farming, check dams and warping.

#### Re-vegetation

The general opinion of experts in reservoir sedimentation management is that re-vegetation is not an effective reservoir sediment management technique. This does not mean that it should not be implemented for other purposes, such as prevention of soil loss that is critical for food security. It merely means that other reservoir sediment management techniques are usually more economical, viewed purely from a reservoir sediment management point of view. In the JCD watershed, there has been relatively little development and the natural vegetation is generally unchanged. Consequently, re-vegetation is not considered to be necessary.

#### Check dams

Check dams have been implemented as a sediment management measure upstream of many dams. The reduction in the river's sediment transport capacity in the reaches immediately upstream of check-dams results in sediment deposition. They require regular maintenance to maintain their effectiveness. Check dams are generally applied in series to increase the amount of sediment they can capture. It is noted that even if they are filled with sediment, placing a large number of check dams in series in a river may reduce its sediment yield. To accomplish such a goal, it is necessary to arrange the dams in a manner that will significantly reduce the energy slope in a river, and the corresponding sediment transport capacity. Check dams are most effective in catching large sediment particles, and are less effective in catching small particles. Some check dams have been constructed in the JCD watershed by the Ministry of Forests. These have some benefit but are unlikely to significantly reduce the sediment inflow to the reservoir during heavy rainfall events.

The existing sediment beach upstream of the reservoir is already an efficient trap for sediment, trapping more than 10 m of sediment thickness above the reservoir level. Check dams would likely result in a small marginal improvement in sediment trapping efficiency, but would be at risk of washout and would require mobilization of equipment and resources to a location with no road access. These resources may be at risk if they cannot be demobilized in time when storms occur.

### 5.4.3 Reservoir Sediment Routing Options

The best known modern techniques to minimize the amount of sediment deposited in reservoirs are bypassing, sluicing and density current venting.

#### Bypassing

The objective of the "bypassing" option is to divert sediment carrying waters around reservoirs and to prevent them from entering and depositing sediment in the reservoirs. Various schemes may accomplish this goal, but the most common entails the use of bypass tunnels. However, bypassing may also be accomplished by modification of river channels and using off-channel storage.

When floods containing high sediment loads are present, the diversion structure diverts the flow for discharge downstream of the dam. During average flow conditions, the water is allowed to flow into the reservoir. Average river flow contains relatively low sediment loads, resulting in a smaller volume of deposited sediment within the reservoir.

This option is not considered to be appropriate, because bypassing the sediment would be expensive and difficult to manage at JCD.

### Sluicing

Sluicing is an operational technique in which sediment laden flow is released through a dam before the sediment can settle. In essence, the sluicing concept consists of maintaining high velocity and high sediment transport capacity in the water flowing through a reservoir that will prevent or minimize the amount of sediment depositing in the reservoir. Ideally, sluicing should be designed to balance the long-term volume of sediment entering the reservoir with the volume that is discharged downstream. This method is considered to be infeasible because the JCD reservoir does not have a high capacity low level sluice.

### Density Current Venting

When water with a very high sediment concentration flows into a reservoir it is possible that the density of the sediment laden water is higher than the water contained in the reservoir. Depending on local conditions, very little mixing might occur between the density current and the reservoir water. This means that a dense, sediment laden current flows along the bottom of the reservoir towards the dam.

Deposition of this sediment can be prevented by releasing the density current downstream of the dam. This is accomplished by installing low level gates at the dam. When these gates are opened as the density current approaches the dam, the high sediment concentration water may be released downstream of the dam. This means that the relatively heavy sediment load contained in the density current is discharged downstream of the reservoir, without depositing in the reservoir. The process is known as density current venting. The facilities for density current venting are not available at the JCD. This option is also not suitable at JCD because it would require a relatively large water release during the wet season, a release that may jeopardize the water supply by releasing too much water before the dry season.

## 5.4.4 Sediment Removal Options

Reservoir sediment can be removed by means of dredging, hydro-suction, dry excavation, drawdown flushing and/or pressure flushing.

### Dredging

As applied in reservoir sedimentation management, dredging generally consists of using hydraulic pumps on barges with intakes down to the reservoir bed. The pumps create enough suction to remove deposited sediment from the reservoir bottom. If the deposited sediment is cohesive or coarse it is difficult to remove by suction only. In such cases cutter heads may be required at the suction end of the pipe. Cutter heads loosen the deposited sediment, allowing it to be entrained by the suction created at the end of the dredge line. The dredged sediment can be transported in a slurry pipeline to a deposition area. This option is feasible at JCD.

A suction dredge with a cutter head would be the most efficient type of dredge equipment. Suction dredges would produce slurry with varying percentage solids by weight depending on discharge length, material being suction, and pipe diameter. It is possible to mobilize the sediment without draining the reservoir if the operation is managed appropriately. Dredging the sediment in the dry season would likely increase the risk of water rationing or a water supply failure. Wet season dredging would be preferred. Sediment control measures, such as silt curtains, will be necessary to ensure that the dredging does not affect water turbidity at the intake to such an extent that it causes an upset at the WTP.

### Dry Excavation

Removal of deposited sediment by dry excavation consists of draining the reservoir and using conventional excavation equipment to load deposited sediment into trucks for removal from the reservoir. This approach to sediment management is usually suited for implementation at flood control dams and their reservoirs. In such cases it is often required that the reservoir remain empty or almost empty for most of the year. However, the reservoir at JCD cannot be drained due to water supply requirements.

Excavation of the sediment above the water line may be possible if the sediment is transported across the reservoir by barge and then transferred to trucks. Construction of a new road access to the upper watershed could also be considered. These methods have issues related to the environmental impact of a new road through the upper watershed, the risk of contaminating the reservoir with hydrocarbons, and the unlikely viability of high traffic volumes of heavy equipment along the existing Millet road. However, this option is fatally flawed because excavation would be limited to the beach areas above the water line, or to small isolated areas below the water line.

Excavation of the beach above the spillway elevation does not improve the water supply reliability. It will only help to extend the remaining operating life of the reservoir. WASCO would be forced to develop a new water source for the dry season. Additional excavation below the spillway elevation would require additional containment measures to excavate below the water line, considering that the reservoir is usually full to the spillway elevation. This containment may not provide a safe working environment in the event of a storm. Therefore, excavation of the sediment is not a viable option because it would not improve the water supply reliability and may otherwise be unsafe.

### Hydro-suction

Hydro-suction is a technique that employs dredging equipment with sufficient hydrostatic head over a dam to create suction at the upstream end of the discharge pipe. This suction is then used to remove the deposited sediment. The upstream end of the pipe is typically moved around with a barge to remove sediment throughout various parts of the reservoir. A limitation to this kind of sediment removal is that it is principally used over short distances. The method would likely be ineffective at JCD where the majority of the sediment is located more than 1 km from the face of the dam.

Flushing of silt sediment near the dam face to the downstream Roseau River may be possible and economical by hydro-suction dredging, and the morphological effects will likely be manageable or result only in short-term effects – assuming that the sediment is released during high flow. This assumption that the morphological effects are manageable has not been studied in detail.

### Drawdown Flushing

Drawdown flushing is a technique requiring complete drawdown of a reservoir to re-suspend deposited sediment and flush it downstream. Therefore, an important requisite for drawdown flushing is that low-level gates of adequate size should be present in the dam. The gates should be large enough to freely pass the flushing discharge through the dam without upstream damming. The water supply intakes at JCD would become inoperable if the reservoir level was drawn down to facilitate sediment flushing, and there are currently no low level gates to draw down the reservoir. Consequently, this option is not viable.

### Pressure Flushing

Pressure flushing is a technique that is used to remove sediment directly upstream of an outlet. It is implemented by opening the outlet without drawing down the water surface elevation. This action results in water accelerating for a limited distance upstream of the opening, causing removal of sediment for a limited distance upstream of the outlet. This method has the same drawback as drawdown flushing so it, too, is not viable at JCD.

## 5.4.5 Sediment Transport Options

### River

Key stakeholders are opposed to the release of sediment to the downstream river. The WRMA explained that the downstream river is already stressed by sedimentation from agricultural activities, and that the nearshore fishery may be at risk by further sediment loading to the river. Flushing of sediment to the river was therefore rejected as a viable option to de-silt the reservoir.

River transportation of the sediment may potentially be more acceptable the sediment was recovered further downstream. One location where this may be possible is near the confluence of Roseau River and Millet River, although this location would have limited capacity to store sediment. This option would need to rely on other locations for permanent disposal of the sediment. The sediment would therefore be handled once at the reservoir, handled a second time to recover the sediment from the river, and likely handled a third time when it is transported by truck to other permanent disposal locations. It was therefore assumed that this option may be possible if more economical solutions are not available.

### Pipeline

Pipeline transportation is ideally suited to dredging, because a dredge will initial pump the sediment to a pipe. Pipeline unit costs to transport sediment are typically less than trucking.

### Truck

Truck transportation of the sediment is possible after initial dredging and subsequent dewatering. Truck transportation would require a pipeline to a dewatering or decant facility to reduce the water content of the dredge slurry. There are a number of technologies to achieve this, at a variety of potential costs. Another consideration for truck transportation is that the Millet Road is not suitable for high traffic volumes of heavy haul equipment. It was assumed that high volume heavy equipment traffic would be unacceptable to the Millet community due to the likely road damage and social impacts. The feasibility of road improvements has not been evaluated in detail. A preliminary assessment identified the potential for a new access road through Dame de Traversay to bypass a portion of Millet, plus additional road improvements at two road bends in Millet that may need to be improved. The design and evaluation of a new access road have not been included in this report and will need to be further developed if a business case is developed.

## 5.4.6 Sediment Disposal Options

A variety of potential disposal locations were considered. Some options were assumed to be unacceptable, including:

- Offshore fill areas would incur a variety of environmental and socio-economic impacts, so this option would require a strong economy-based rationale to justify the environmental damage to offshore reefs, commercial fishing, and possible tourism impacts.

- Beach enhancement at Roseau Bay may be possible, but would likely be viewed by stakeholders as undesirable. This option could be considered if more economical solutions are not available.

The remaining disposal options for large or small deposits may all be considered. However, smaller deposit sites would not likely be considered for pipeline transportation. Potential sediment deposit area (SDA) locations were discussed with stakeholders during the initial consultation workshop (October 29, 2014). Some potential sites are shown on Figure 21.

Three potential SDA locations were considered to be sufficiently large for long-term high-volume sediment management operations:

- Old construction laydown area is within a small valley near JCD. The laydown area was originally disturbed during construction of the dam in the 1990s. The area is currently un-reclaimed, but there has been some re-generation of forest vegetation. This location has an ultimate sediment storage capacity of about 2 million $m^3$, which is sufficient storage for all of the existing reservoir sediment plus some additional future reservoir sediment, providing capacity for about 20 years. The sediment would be contained within the small valley above the Roseau River. The sediment deposit would not likely be visible to nearby residents, although it may be visible from local trails along the valley ridge near Dame de Traversay. There is no other development in the small pocket valley where the old laydown area is located. This location is about 1 km from JCD. About 34 ha (85 acres) of private land will need to be purchased.

- The valley along Millet Road (between JCD and the Millet River) was considered for sediment disposal. This valley has sufficient capacity for long-term disposal, but is currently utilized by local farmers. Disturbance to this valley likely has social and gender impacts that should be avoided if other feasible locations are available. The local residents would lose their capacity to farm near their homes, most of which is managed by women who sell their produce at the market each week. The loss of income would likely have significant negative consequences on local families.

- The lower Roseau River valley could be considered for long-term sediment deposition. The south side of the Roseau River is currently privately-owned agricultural land with banana and other crops. The crop land would need to be purchased and cleared for an initial sediment management area at least 20 ha (50 acres) and would likely need to be expanded by 20 ha every 5 years. About 100 ha of private land should be purchased for the containment area plus ancillary work areas. The sediment will need to be contained by engineered containment berms plus a decant system to manage the slurry water. The pipeline distance to this general location is about 8 km.

Other smaller areas were also identified by stakeholders as potential sediment deposit areas. They include the potential development of sports fields whereby the sediment would be used to create a uniform surface, plus private properties where the landowner is improving the land.

Altogether, there are many potential SDA locations. The large properties would be considered for long-term sediment storage of large volumes transported by pipeline. Small properties would likely require trucking from a dewatering area or a large SDA.

The old construction laydown area has a large containment capacity and is located near the reservoir. This site is ideal from an economic perspective because the required pipeline would only be about 1 km, although a new access road will likely be needed to support high volume traffic of heavy equipment if some of the sediment is re-used for other purposes (e.g. sports fields). The design and evaluation of a new access road have not been included in this report and will need to be further developed if a business case is developed.

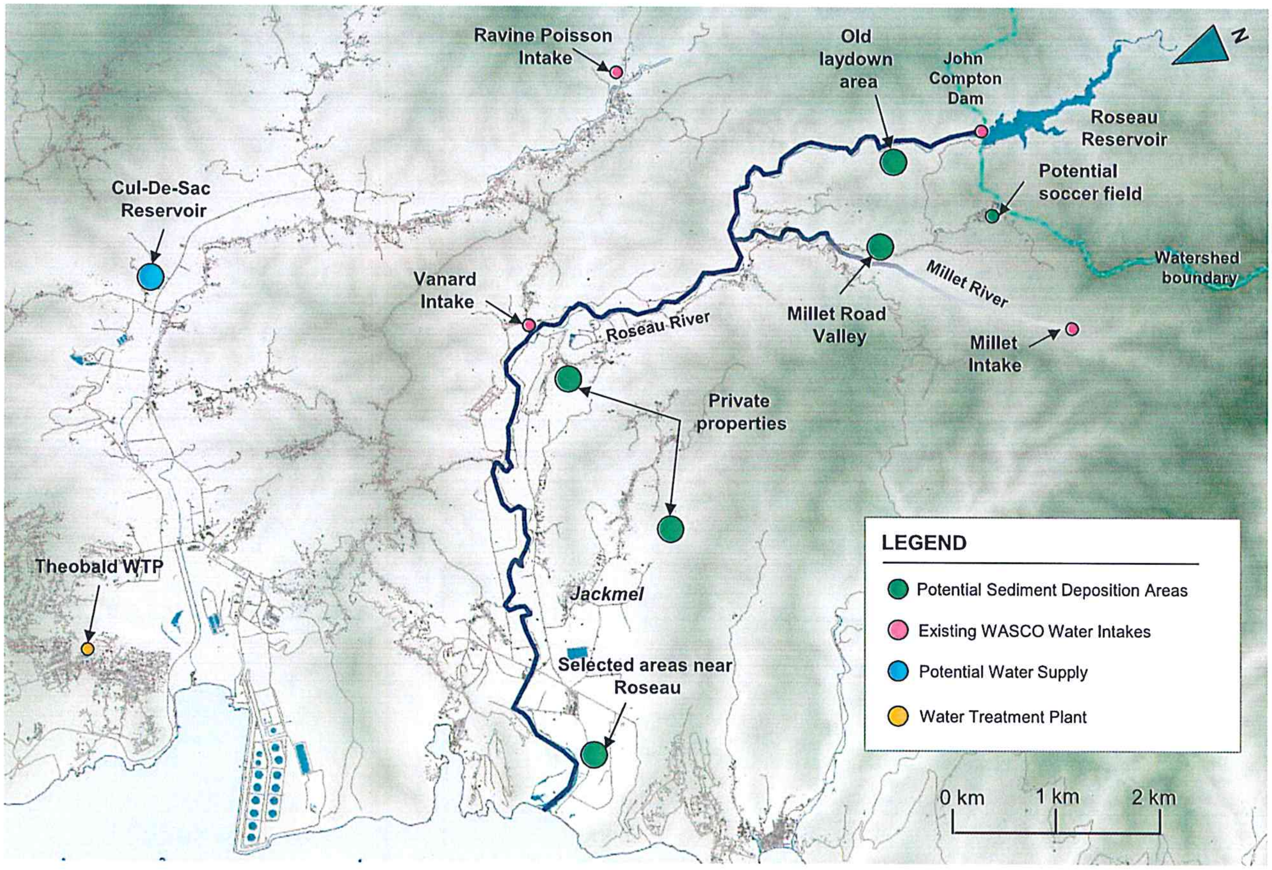



*Figure 21: Potential Sediment Disposal Locations*

# 6.0 ASSESSMENT OF BENEFITS AND COST

Selected water management options are compared in the following sections in terms of the overall benefits and cost. The assessment is biased in terms of the preferred water source, Roseau River at John Compton Dam (JCD), and the logical choice of de-silting the reservoir by dredging.

## 6.1 Preferred Water Source

The existing water source at JCD is the preferred water source because it is a high quality source that is not easily replaced. The Roseau River upstream of the dam is an undeveloped natural tropical rainforest that is ideal because it is relatively unthreatened by contamination from human activities. There are no other readily-available sources that can provide the equivalent water supply in a cost-effective and reliable manner. Some of the water demand may be offset in the future by water conservation measures or by loss management within the distribution system.

## 6.2 De-silting Method

### Dredging

The project will need to involve dredging of sediment from the reservoir as a key component of the selected plan (see Figure 22), because water abstractions from JCD cannot be restored to 10 IMGD without dredging. The current sustainable water supply from the dam is 6 IMGD, and additional storage at the dam is not sustainable because future sedimentation at an annualized rate of 75,000 m$^3$ per year will limit the future operating life of the reservoir.

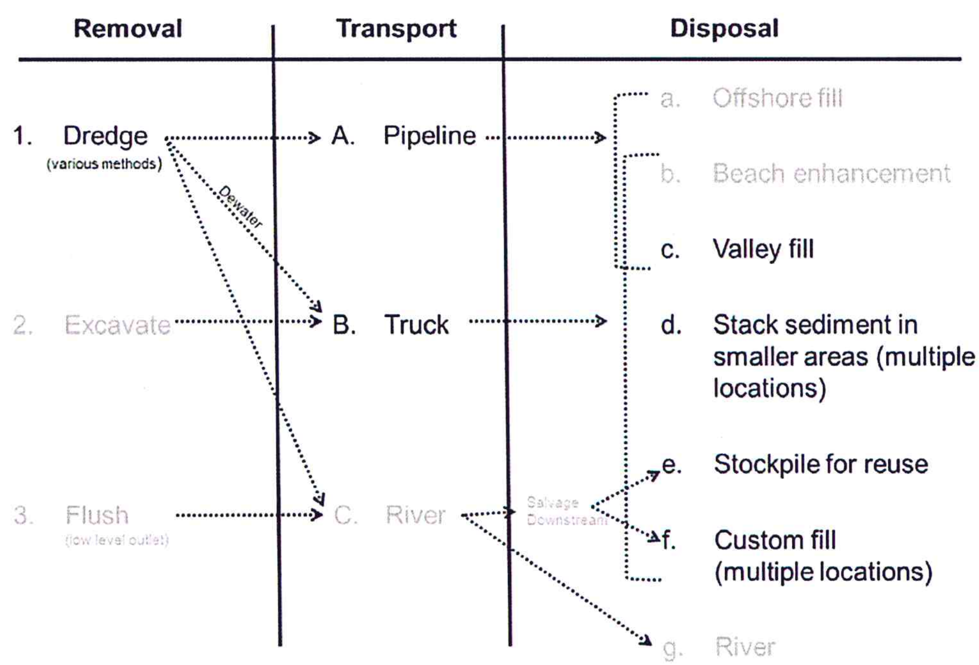



*Figure 22: Feasible Sediment Management Options*

### Sediment Transportation and Disposal

The dredging solution will require a pipeline to either a sediment disposal area (SDA) or to a dewatering facility. Overall, pipeline transportation to a permanent SDA will likely be the most economically efficient method of transporting the sediment, as it avoids double-handling of the sediment that would otherwise be required for trucking. This assumption is dependent on the relative distance to the SDA and the dewatering facility, should they be in different locations. A trucking scenario would require a dewatering facility near the dam after the sediment is dredged and piped to the dewatering facility. The nearest feasible site for a dewatering facility is the Old Laydown Area downstream of the dam. Therefore, dredging to the Old Laydown Area as a permanent SDA is expected to be the more economical solution because it avoids the additional trucking costs.

The SDA is expected to have a limited design life, based on the storage capacity of the area and the pace of dredging. After the SDA is filled with sediment, a new SDA location will be needed. The Old Laydown Area has a capacity of about 2 million $m^3$, sufficient for the existing reservoir sediment but not sufficient for all of the future sedimentation that may occur over the coming decades. The timing of this future sedimentation and subsequent dredging is uncertain because large storms may occur at any time or not for several years.

The management options for replacing the SDA in the future are:

- Construct a longer pipeline to a new SDA, most likely located in the lower Roseau valley;
- Truck sediment from the Old Laydown Area to a new SDA near the end of the design life; and
- Gradually re-use sediment by mining sand resources from the Old Laydown Area as it fills.

## 6.3 Dredge Capacity

A key consideration for de-silting the reservoir is the selected dredge capacity. The pace of sediment dredging influences the cost of the project, the expected life span of the SDA, the potential for opportunistic benefits to the local economy, and the ability of WASCO to respond to future sedimentation events.

Dredging at a relatively rapid rate will likely require larger equipment and a specialized contractor. The majority of sediment may be dredged within 3 years using a 30-inch dredge, but this is not a sustainable solution because the dredge would need to be re-mobilized after every major sedimentation event in the future. There are no feasible options to prevent future sedimentation.

A more sustainable approach is to dredge the reservoir sediment at a slower measured pace and to continue dredging indefinitely. This approach has the flexibility to absorb shocks such as sediment from a large storm that blocks the lower intake port again. A large dredging operation would need to remobilize at high cost when a future storm eventually buries the lower intake port again. Instead, a small dredging operation would simply need to shift the location of the dredge barge to daylight the lower intake port on an emergency basis. The small dredging operation would utilize a common 10-inch size of dredge. The intake port could be restored within about 21 days, depending on the number of hours per day that the dredge is operated. By comparison, the temporary loss of the lower intake port would leave WASCO with 40 days minimum water supply (assuming an abstraction rate of 10 IMGD and reservoir inflow of 5 IMGD). A large dredge likely cannot be mobilized within 40 days of a major storm. The measured pace strategy therefore results in a more resilient water supply operation. A small dredge operation will also likely provide permanent local employment because local crews can likely be trained to operate the smaller dredge over the long term.

The benefit-cost assessment compares a large dredge configuration to a small continuous long-term dredging operation. Although a large dredge operation could remove all the existing sediment within 3 years, the capital cost of a much larger 24-inch to 30-inch dredge is expected to be almost triple the cost of a small dredge operation, assuming that the large dredge must be purchased and stored on-site after the dredging is completed. A smaller 10-inch dredge would need to be operated indefinitely, but could respond to future sedimentation events by simply moving the barge and removing sediment on a priority basis. The small dredge capacity would need to be more than the estimated long-term sediment yield.

The (small) dredge capacity should be 1,200 $m^3$ per hour slurry (i.e. solids plus water), assuming approximately 21% solids by weight – equivalent to approximately 130 $m^3$ per hour of solids. The dredge has the potential to handle up to 200 $m^3$ per hour of solids depending on the proximity and type of sediments. The volume of sediment dredged from the reservoir at this capacity is expected to be 112,000 $m^3$ of solids per year, which is greater than the estimated 75,000 $m^3$ sediment yield. The dredge capacity assumes that the dredging would only be allowed to occur when the reservoir is full. This limits the dredge availability to about 80% of the time from July through November when a drought is unlikely to occur. The dredging capacity can also be adjusted by operating for more than 8 hours per day.

For the continuous operation of a small dredge, the SDA is expected to be full within 20 years assuming that the sediment is not re-used. Sediment re-use at off-site locations will extend the life of the SDA.

## 6.4 Future Water Supply Increases

The original JCD design basis for water supply was 10 IMGD. Water demand in the future may result in increased water abstractions above the current design limit of 10 IMGD. A water demand forecast was not part of the scope of work.

The future water demand may increase beyond 10 IMGD. The existing reservoir is sufficient to supply additional water, but at reduced reliability. The available options to increase the water supply to 12 IMGD include raising the dam by about 10 m, providing additional off-site water storage, or to develop a new dam along a different river.

## 6.5 Environmental, Socio-Economic, and Gender Considerations

The environmental, socio-economic, and gender issues or opportunities should be considered as part of the evaluation of management options. Several issues and opportunities were identified by the project team based on interviews with various stakeholders, on the interpretation of available literature, and based on the project team experience in Saint Lucia. There are several key considerations:

- A secure water supply is important to the economic and social welfare of Saint Lucia. In 2014, a drought forced WASCO to ration the water supply from Roseau Reservoir (due to sedimentation). The rationing avoided a more pronounced water shortage that may have affected many businesses, including more than 200 hotels and resorts during the peak tourist season.
- The upstream watershed of Roseau Reservoir is a valued natural resource as the water source for about half of the island population. The watershed is currently an undeveloped and pristine environment that delivers high quality natural waters for treatment and distribution. Any development within the watershed would encourage further development that may threaten the natural quality of the water source.

- Any de-silting plan should consider local employment as an option for staffing the project, subject to required skills or training.
- The gender role of women in Millet and other local areas near the John Compton Dam includes small scale agriculture in the valleys adjacent to the community. Disturbances to the valleys (e.g. for storage of sediment deposits) may affect the livelihood of families.
- Local traffic controls will be important for any de-silting plan. The pattern of daily activities in the communities will need to be considered to avoid unnecessary impacts due to heavy equipment traffic. Millet village residents would generally prefer to restrict haul truck traffic along the Millet Road to specific days of the week or times of the day. Local produce is shipped to markets on Thursday and Friday. Saturday and Sunday are both days of prayer and church. Week days also have small children walking to the local school along the Millet road in the morning and home in the afternoon.
- Several critical or priority Saint Lucia fauna and flora species are endemic to Saint Lucia and have small population sizes that may be threatened by habitat loss and/or invasive species predation, including but not limited to the Saint Lucia Amazon (Jacquot Parrot) and the Saint Lucia Black Finch. Construction should try to avoid disrupting the habitat and breeding activities of these species to the greatest extent possible. The breeding season for the Jacquot Parrot is documented to occur during the dry season in February and March, but may extend later in the year depending on the prevailing climate.
- Birding tours use local trails near the dam. These tours, and the birds that they are observing, may be disturbed by construction during the peak tourist season from December through June.
- Millet village residents support the re-use of any salvaged woody debris. Woody debris is expected to be a waste product of the reservoir de-silting plan, because there are sunken logs within the reservoir that need to be removed prior to removal of the sediment. These logs are a potential (charcoal) fuel source for local residents.
- Stakeholders support the re-use of sediment removed from the reservoir. These re-use opportunities may include the construction of new sports fields, improvements to local drainage works, road construction, or land improvements for development. In some cases, land improvements may increase the value of the land for development. Several landowners expressed an interest in allowing sediment disposal on their property.
- Stakeholders do not support the addition of sediment to the Roseau River downstream of John Compton Dam. The Water Resource Management Agency (WRMA) of the Ministry of Sustainable Development, Energy, Science and Technology is concerned that the downstream Roseau River is already silted due to downstream agricultural activities. Additional river siltation may affect both freshwater and offshore aquatic life. In particular, offshore fishermen rely on aquatic habitat in Roseau Bay, where the health of coral reefs and other habitat may be affected by additional sediment delivery from the Roseau River.
- Private lands that are disturbed or occupied as part of the de-silting plan may need to be purchased for the project.
- It is assumed that the existing Millet Road would be damaged from long-term regular use by haul trucks and other large equipment. Any road damage would affect local residents.

- New road access may need to be considered for long-term operation of sediment removal and sand/gravel re-use, depending on the selected de-silting plan (outside the scope of this project). Any new road construction may affect local residents due to proximity. The effects may include noise and dust, but may also improve local access. Improved local access may be a benefit for existing residents or developers, but may also have mixed results depending on the needs of local residents.
- An erosion and sediment control plan will need to mitigate disturbances at any selected sediment deposition area.
- Clearing of vegetation for a sediment deposition area, if needed, will have an environmental effect. Appropriate mitigation measures will need to partially offset the effect where possible.
- There is an unused off-channel reservoir with a storage capacity of about 12 million imperial gallons. The Cul-de-Sac reservoir near Deglos was constructed for irrigation projects in 2002. It is available for use by WASCO as an emergency water source.

## 6.6 Short-List of Management Options

Several water management options were considered for the benefit-cost assessment, to illustrate the rationale for selecting a preferred JCD Rehabilitation Plan. The options were grouped by water supply capacity, and the options must all meet the minimum water supply reliability requirements. The options that were compared are:

- Status quo to proceed with no investment and operation of the existing dam to supply 6 IMGD;
- Options to restore the original JCD water abstraction rate to 10 IMGD and provide for long-term sediment management:
  - Small 10" dredge and continuous dredging operation and disposal to the Old Laydown Area;
  - Large 30" dredge and 3-year dredging operation to dispose of all the existing sediment at the Old Laydown Area, and then to demobilize the dredge operation; and
  - Small dredge operation and sediment disposal in the Roseau valley near Jackmel.
- Future options to expand JCD water abstraction to 12 IMGD:
  - Off-channel storage in the Roseau valley near Jackmel plus a small dredge operation;
  - Raise the dam by 10 m plus a small dredge operation;
  - Loss management plus a small dredge operation;
  - Raise the dam, loss management, and a small dredge operation; and
  - New Roseau dam, plus a small dredge operation.

These options were intended to represent the range of feasible, realistic, and/or acceptable solutions. Some options, such as release of sediment to the downstream Roseau River, are not listed due to stakeholder opposition. Unproven options that may supply water in the long term were not evaluated as part of this project – such as desalination, water import, a new dam along a different river, and groundwater supply. The list is not intended to be exhaustive, and does not describe all of the detailed elements for each option.

## 6.7 Assessment Criteria

Several key decision criteria were selected for the purpose of a benefit-cost assessment, based on our understanding of the water supply issues and on the comments provided by stakeholders. Some additional issues or opportunities are not represented among the criteria in an effort to focus on the key issues. The selected criteria are:

- Sustainable water abstraction from JCD, in IMGD;
- Investment dollars, in terms of millions of US dollars represented as a net present value and shown with only one significant digit to avoid biasing any future bidding process;
- Water sales by WASCO, measured as changes to existing sales in $XCD millions per year (accounting for 60% non-revenue water, but not accounting for the marginal cost of additional water treatment), assuming an average $50 XCD per 1000 gallons revenue for water and sewerage;
- Economic benefits to the island of Saint Lucia resulting from improved water supply, as a qualitative assumption by this consultant; the relative benefits for each option are directionally-correct, and the recommendation of a selected de-silting plan is not sensitive to small differences in the estimated economic benefits;
- Potential habitat loss due to vegetation clearing, measured in hectares;
- Roseau River drought riparian releases, measured as a flow in litres per second minimum release downstream of JCD;
- Permanent local employment associated with the project, as a relative scale (not intended to be precise) because the precise number of jobs created is uncertain;
- Land improvement opportunities associated with potential sediment re-use, as a qualitative estimate to differentiate between the existing conditions (i.e. no opportunity) and the short-list of options, which all provide roughly equivalent future opportunity;
- Resiliency to sediment events due to large storms, as a qualitative estimate interpreted by this consultant based on the potential interventions during de-silting operations;
- Climate change vulnerability, as a qualitative estimate interpreted by this consultant based on expert opinion; the assessment ratings indicate the relatively equal improvement of all short-list options to improve the water supply, all of which rely on rainfall in the Roseau watershed and therefore are not immune to extreme changes to future climate; and
- Dam safety, as a qualitative estimate interpreted by this consultant to indicate the likelihood that the dam is capable of passing the 10,000 year flood.

For the purpose of the assessment, the relative importance of the criteria was selected as:

| High (10) | Moderate (5) | Low (3) |
|---|---|---|
| ■ Sustainable water abstraction from JCD<br>■ Economic benefits | ■ Investment cost<br>■ Resiliency (to recover quickly from major events)<br>■ Climate change vulnerability | ■ Water sales<br>■ Habitat<br>■ Riparian flow<br>■ Permanent employment<br>■ Land improvement opportunities<br>■ Dam safety improvements |

Note: relative importance weighting shown in parentheses.

The relatively high importance placed on the economic benefits reflects the overall importance of providing sustainable water abstractions from JCD, assuming that the two criteria are redundant.

## 6.8 Benefit-Cost Assessment

### Benefit – Cost Assessment Method

The assessment of benefits and costs followed a standard multi-criteria decision analysis technique known as Compromise Analysis, a distance-metric method that aggregates the various trade-offs in terms of a performance measure. The performance measure indicates the relative distance from an ideal solution. A performance of 1 indicates a perfect solution. This method avoids the well-documented problems with simple addition of weighted scores, which are prone to unintended bias and discounting of poor ratings.

### Expected Performance of Water Management Options

The small dredging operation, with disposal of sediment in the Old Laydown Area, has the highest rated performance among the options to restore the water supply from JCD. This is due to the relatively low cost, low impact, and high benefits. The resulting ranking of a small dredging operation to the laydown area is not sensitive to changes in weights or to small changes in the individual ratings. The relative expected performance of the water management options are illustrated on Figure 23 and Figure 24, based on the ratings in Table 5. The estimated cost details for the small dredge option are provided in Appendix E. Rough cost estimates for other short-list options are also provided in Appendix E.

The expected performance of Loss Management may change after more information is known about the potential cost to improve NRW from about 60% to 50%.

In the long-term, as customer pressures force WASCO to increase the water supply from JCD, the top ranked option is to raise the dam. This option may be combined with other loss management measures to reduce leakage in the pipe distribution systems, depending on the relative cost of loss management. The resulting maximum sustainable water abstraction from JCD is 12 IMGD.

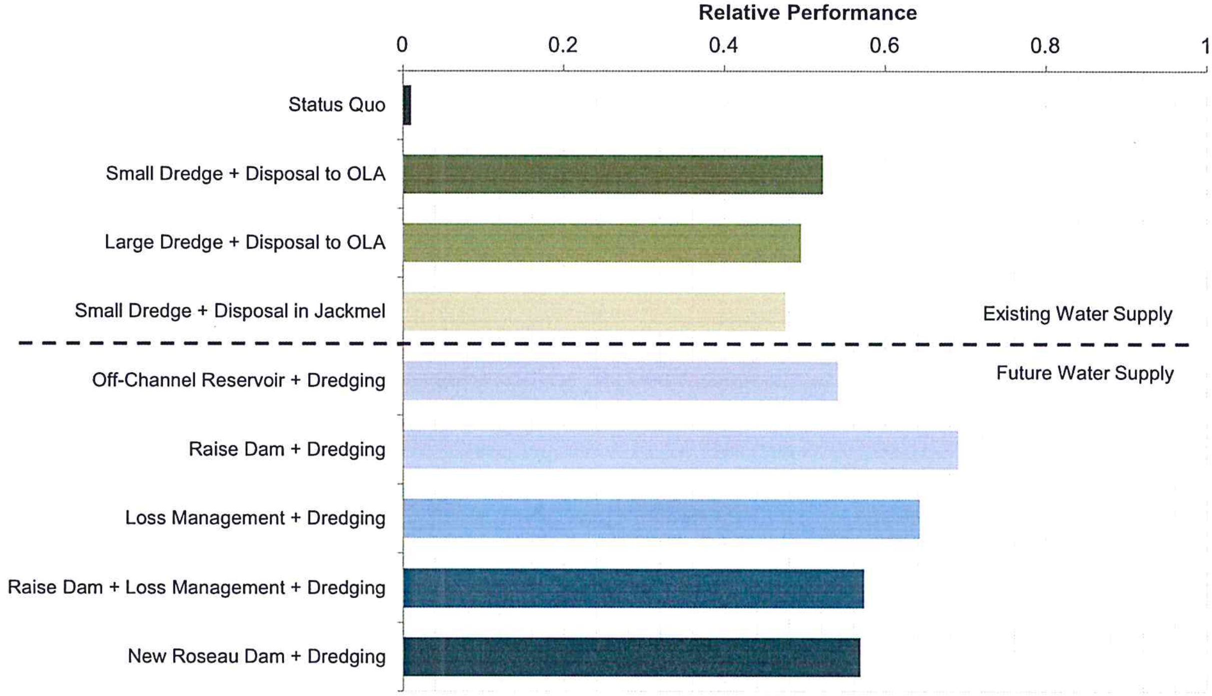



*Figure 23: Relative Performance of Selected Water Management Options for Existing (10 IMGD) and Future (12 IMGD) Water Supply from JCD*

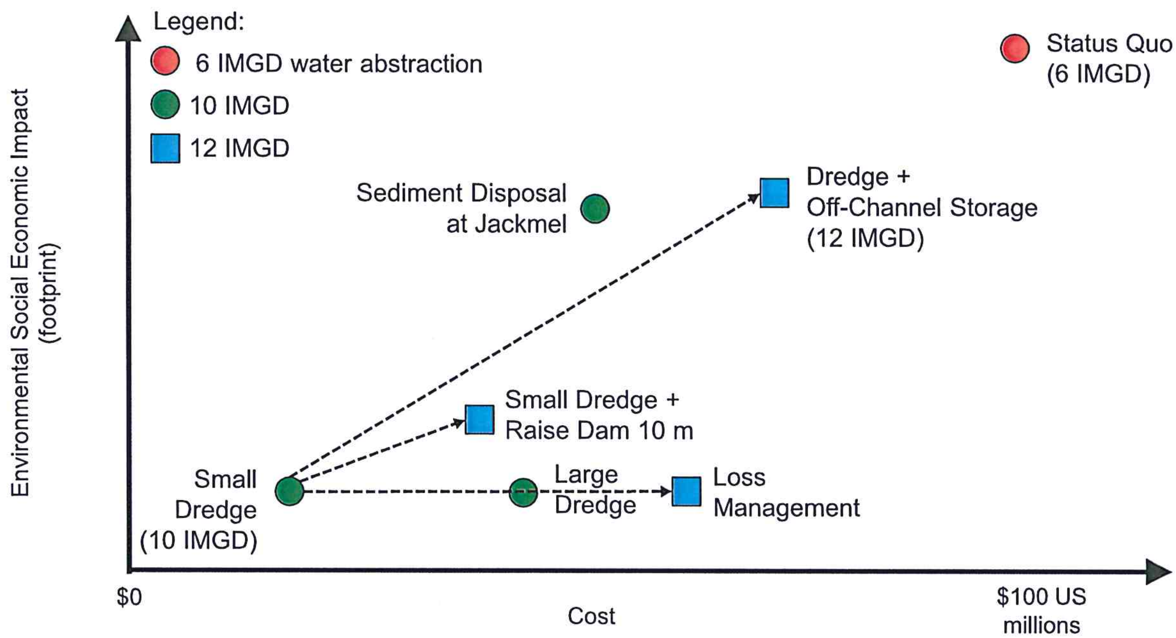



*Figure 24: Summary Comparison of Selected Water Management Options*

**Table 5: Benefit-Cost Assessment Summary Table**

| Criteria | Units | Status Quo | Small dredge, disposal to OLA | Large dredge, disposal to OLA | Small dredge, disposal in Jackmel | Off-channel reservoir plus dredging | Raise dam plus dredging | Loss mgmt plus dredging | Raise dam, loss mgmt, dredging | New Roseau Dam plus dredging |
|---|---|---|---|---|---|---|---|---|---|---|
| Sustainable water abstraction from JCD | IMGD | 6 | 10 | 10 | 10 | 12 | 12 | 10 | 12 | 12 |
| Investment (NPV) | $US millions (1 significant figure) | 0 | -10 | -40 | -50 | -70 | -30 | -70 | -90 | -70 |
| Water sales (change) | $XCD millions/ year | -29 | 0 | 0 | 0 | 15 | 15 | 18 | 36 | 15 |
| Economy | -5 to +5 (qualitative) | -4 | 0 | 0 | 0 | 2 | 2 | 3 | 4 | 2 |
| Potential Wildlife Habitat | ha | 0 | -18 | -18 | -100 | -100 | -30 | -18 | -18 | -100 |
| Roseau River drought riparian releases | L/s | 0 | 10 | 7 | 7 | 10 | 7 | 10 | 10 | 7 |
| Permanent employment associated with project | # local jobs (relative only) | 0 | 10 | 5 | 10 | 10 | 10 | 10 | 10 | 10 |
| Land improvement opportunities | 0 to +10 (qualitative) | 0 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Resiliency to sediment events | 0 to +10 (qualitative) | 0 | 7 | 5 | 7 | 9 | 7 | 7 | 7 | 9 |
| Climate change vulnerability | -5 to +5 (qualitative) | -5 | 3 | 3 | 3 | 4 | 4 | 3 | 4 | 4 |
| Dam safety | 0 to +10 (qualitative) | 8 | 8 | 8 | 8 | 8 | 10 | 8 | 10 | 8 |

# 7.0 RECOMMENDED JCD DE-SILTING AND REHABILITATION PLAN

## 7.1 Overview

Together, the site-specific conditions of JCD and the current water abstraction of about 10 IMGD results in a preferred plan to dredge sediment from the reservoir at a measured pace over the long term, piping the sediment to the Old Laydown Area as the preferred SDA, and managing emergency water sources to reduce the frequency of water rationing. The sediment storage area has a finite capacity, thereby providing some incentive to re-use sand and gravel sediment at off-site locations to avoid the additional future capital investments of developing another large-scale sediment deposit area. Finally, WASCO has the opportunity to provide additional local economic benefits if the dredging contract is arranged as a permanent operation to gradually recover the original reservoir storage capacity. Infrastructure requirements are illustrated on Figure 25 and Figure 26.

The majority of the project consists of de-silting the reservoir. Removing the sediment from the reservoir and placing it in the SDA will involve the following activities:

- Hauling dredge equipment to the dam via Millet Road;
- Installing a silt curtain at the upper intake when performing dredging within the vicinity of the dam. Implementing other contingency measures at the WTP to protect the water supply during dredging;
- Dredging the reservoir sediment from a barge;
- Removing woody debris from the reservoir concurrently with dredging;
- Implementing dredging practices that minimize sediment disturbance in an effort to protect the reservoir intakes;
- Pumping and piping dredge slurry to the SDA located at the Old Laydown Area during the wet season, to avoid drawing down the reservoir unnecessarily during the dry season;
- Containing dredge slurry at the SDA by constructing a starter dyke followed by constructing and raising the containment dykes, including temporary diversion paddocks, filters, drains, and erosion protection;
- Re-activating the lower intake port after sediment is cleared from the face of the dam;
- Constructing a water decant structure for discharge of acceptably clean water to the river; and
- Managing the deposition of the sediment in the impoundment to select and separate the usable material (for dyke construction and re-use).

Additional construction work on the emergency water sources will involve the purchase of a temporary Aquadam structure for the Vanard intake, and installation of a perforated pipe gallery intake at both the Ravine Poisson and Vanard intakes.

The preferred solution avoids or mitigates key stakeholder concerns, is cost-efficient, and has the potential to provide an economic return to Saint Lucia if the dredging is staffed and managed locally. The plan will also facilitate future water supply increases up to 12 IMGD if the dam is raised by about 10 m.

Finally, the following management improvements are recommended:

- Dam safety inspections and reviews will need to be implemented at both JCD and the SDA as per international standards.
- A business plan for sediment re-use will need to be developed, accounting for the local demand for sand aggregate, potential concession conditions, and government policy related to aggregate royalties.
- A Source Water Protection Plan (SWPP) is recommended to help manage the source water quality and sediment yield from the catchment upstream of JCD, including landslide stabilization; and
- An Extreme Weather Management Plan (EWMP) describes the emergency response measures during extreme weather, to document the rules for triggering water rationing after the lower intake port is re-activated, to define the methods of water rationing, and to document how emergency water sources will be used.

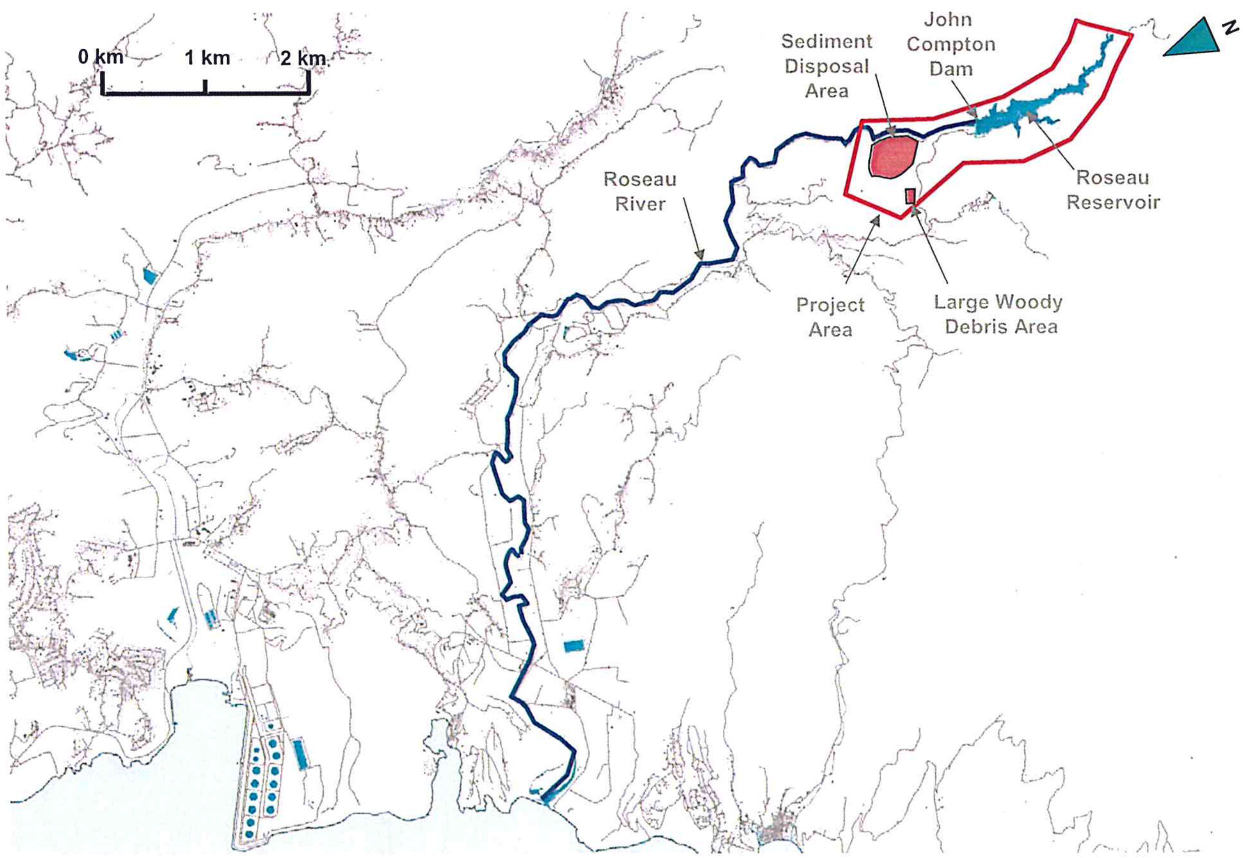



*Figure 25: De-silting Project Area*

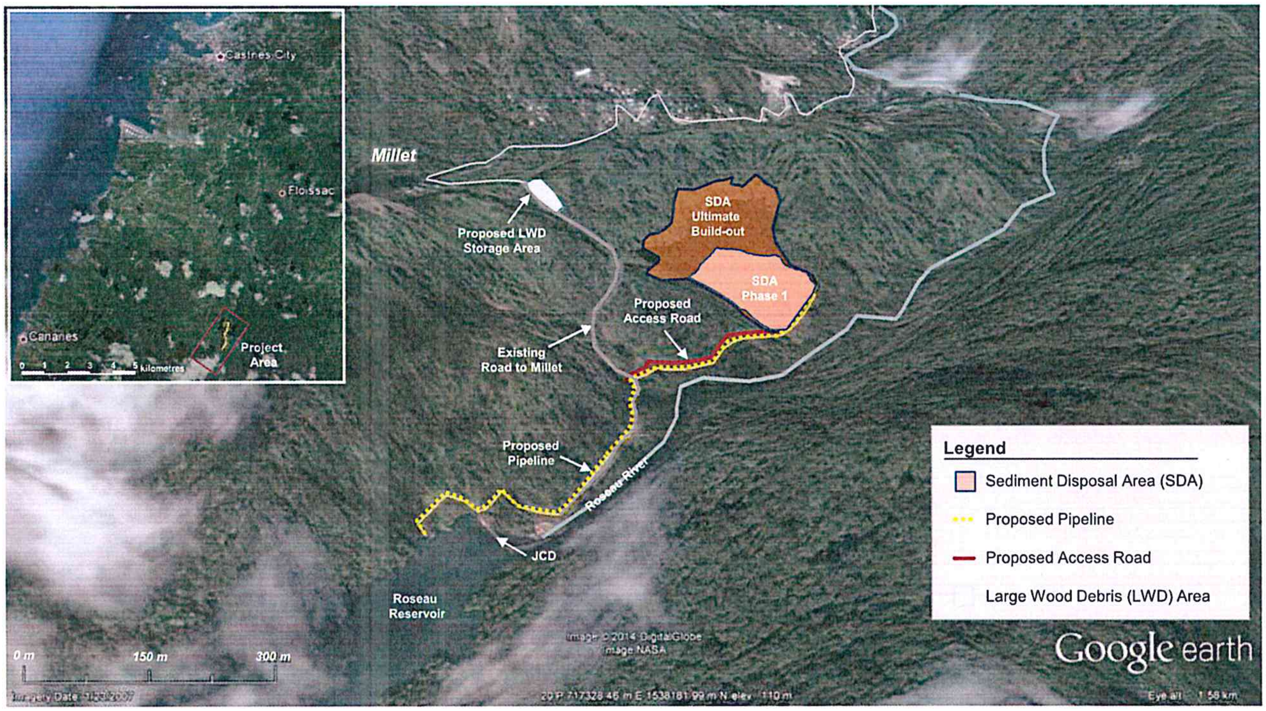



*Figure 26: Location of De-Silting Infrastructure*

## 7.2 Sediment Budget

The sediment budget defines the required pace of dredging for maintaining the reservoir storage capacity, and to determine the expected life span of the SDA. The following assumptions were used:

- There is at least 1.5 million $m^3$ of sediment in the reservoir or on the upstream beach;
- Typical sediment yield captured by the reservoir is 5,700 $m^3$/year when no large storms occur;
- Hurricanes similar to Tomas (2010) are conservatively assumed to occur once every 20 years resulting in up to 1 million $m^3$ of sediment being delivered to the reservoir;
- Tropical storms (TS) similar to Debby (1994) are conservatively assumed to occur once every 10 years resulting in up to 0.2 million $m^3$ of sediment being delivered to the reservoir;
- Dredging operations take place during the wet season from July to November (inclusive);
- Dredge availability was estimated to be 79%, based on historical records. The remaining 21% of time is unavailable, because the use of water for dredging may result in reservoir drawdown below the spillway elevation;
- Dredge utilization is expected to be approximately 30%, (i.e. 30% of time when dredging is available) taking into consideration dredge down-time for maintenance and 8 hour shift lengths;
- Dredged slurry is assumed to approximately 21% solids by weight and a density of 1,920 kg/$m^3$;

- Dredge capacity should be 1,200 $m^3$ per hour slurry (solids and water), or 130 $m^3$ per hour solids at a distance of 1 km from the boat launch; and
- Dredge sediment budget is 112,000 $m^3$ per year sediment removal, based on expected dredge availability and utilization. The dredging rate may be increased by operating more than 8 hours per day when dredging is available.
- Sediment deposit area (SDA) has a full build-out capacity of 2 million $m^3$;

## 7.3 Dredge Infrastructure

The recommended dredge operates by pumping the sediment as slurry and transporting the slurry via pipeline to the deposition area. The suction dredge pump is preferred to a clam-shell or open head excavator to minimize the turbidity that will be created in the reservoir. Suction dredging will require specialized equipment which will likely need to be shipped and hauled to the dam site in a 40 foot shipping container. The dredging operations are expected to involve the following:

- A 10-inch diameter portable suction dredge with a cutter head operating on a custom-made barge.
- The dredge pump and barge will be transported to the reservoir and assembled at the boat ramp.
- The operation will require support facilities such as a boat, trucks, a diesel power supply (on shore), crew facilities, etc.
- The barge and dredge will be capable of moving about the reservoir to where the sediment removal is required, up to 2 km from the boat launch.
- The dredge pump will connect to a flexible HDPE pipe system which will be floated on the reservoir surface. The floated pipe will lead to a booster pump installed on a pontoon scow floating on the reservoir. A pipe from the booster pump will lead to the shore near the boat ramp and will be connected to a buried HDPE pipe within the access road right-of-way to the SDA, a distance of up to 1,500 m.
- A booster pump will be floating on the reservoir at a distance no greater than 1,000 m from the dredge. This will allow the dredge to maintain a suitable solids production rate to meet annual goals. A booster pump may not be required at the start of dredging operations, because the deposition area will be about 30 m below the level of the reservoir. A booster pump will become necessary to deliver the slurry to the deposition surface as the deposition area is filled and the working surface of the deposited sediment rises.
- Diesel pumps for the dredge will be re-fueled periodically from a fuel truck that will travel on Millet Road.

## 7.4 Sediment Deposit Area

The recommended sediment deposition area is approximately 1 km downstream of the JCD on the left bank of the Roseau River, where the original dam construction contractor had a laydown area. This Old Laydown Area was disturbed during the construction of the dam, but there has been some regrowth of vegetation. The deposition area will be developed by constructing an embankment, or containment dyke, on the downhill side of the laydown area but uphill from the river.

An initial starter dyke and divider dykes will be constructed using local earth materials from the containment dam area. The containment dyke will then be raised by placing relatively coarse sand fill on the downstream face of the dyke, as shown schematically on Figure 27. The coarse sediment will be spigotted as slurry into the divider dykes on the south end of the impoundment. The drained sediment will be used as compacted fill on the starter dyke in increments to raise the containment dyke. The containment dyke will be incrementally raised as the impoundment fills with sediment from the reservoir.

The dyke will be constructed to detailed specifications, including seismic loading requirements and flood containment requirements due to runoff from uphill areas. The dyke will have a relatively steep downhill embankment slope and internal filters and drains to ensure that the embankment is stable under all loading conditions. A decant structure will be required to remove excess water. The decant structure will incorporate a riser pipe with progressively higher intake ports connected to a horizontal discharge pipe in the foundations of the dyke. The downstream face of the dyke will be protected from erosion as needed.

An emergency spillway structure will convey an extreme flood event beyond the 100-year event to protect the sediment disposal dyke structure. Protection of the sediment disposal dyke against extreme flood events is required to minimize the potential for a large failure which would deliver large amounts of sediment downstream. Any extreme flood events beyond a 100-year event would potentially result in the release of turbid water downstream of the sediment disposal area. No mitigation is proposed downstream of sediment

The maximum build-out configuration of the containment area is expected to be approximately 50 m high (119 m above sea level), or about 50 m below the top of the overlooking ridge. The volume of sediment that can be stored in the impoundment is about 2 million $m^3$ as described in Table 6. A portion of this volume is expected to consist of fine sediment suspended in water, plus a large sand beach. The sand beach can likely be accessible for re-use. About 0.6 million $m^3$ of sand will likely be inaccessible within the containment dyke.

SDA infrastructure is the major civil engineering component within the Rehabilitation Plan. The sediment containment dyke (and appurtenances), in particular, is an engineered dam that must be certified and managed. The design provided by Golder provides for the full build-out future condition of 2 million $m^3$ of sediment storage, providing design details for the initial 1.2 million $m^3$ of sediment storage. The SDA engineering design basis can be summarized as follows:

- Freeboard sufficient for 100-year stormwater containment, plus conveyance capacity for more than the 100-year stormwater peak flow;
- Factor of safety of 1.5 for geotechnical stability, assuming typical engineering properties for compacted sand; and
- Factor of safety of 1.1 for geotechnical stability during earthquakes, based on a maximum acceleration of 0.33 g.

Configuration of the SDA includes a number of design features that were optimized and otherwise arranged for specific purposes. The following is a summary explanation of the design (drawings and specifications have been delivered separately):

- The centerline alignment for the initial starter dyke maintains a minimum 10 m setback from the future full build-out configuration;
- Design details have been provided for the dyke configuration up to 1.2 million $m^3$ sediment storage capacity;

- The long-term expansion from 1.2 million $m^3$ to 2 million $m^3$ is assumed to utilize dyke raises that are inside the initial dyke alignment. This optimizes the short-term sediment storage capacity, and is feasible provided that sand spigotting from the dyke results in competent foundation conditions. This is most likely the case, but will need to be verified during operations.
- Three smaller "paddocks" are proposed for material handling to preferentially select suitable sand dredge material for dyke raises.
- The decant structure is located far from the dyke spigot locations, and opposite the paddocks.
- The borrow source for the initial starter dyke has been tentatively located along the valley wall adjacent to the Old Laydown Area. This located was selected instead of the relatively flat Old Laydown Area as a contingency, assuming that the Old Laydown Area contains some unsuitable materials for dyke construction.
- A minimum 5 m dyke width is indicated. Additional space for equipment access may be achieved (as needed) along the inside face of the dyke based on sand spigot operations selected by the contractor.
- The pipe alignment from the dredge to the SDA will be along the existing road, with an appropriate road crossing configuration.
- Temporary pipe and local access road locations will be at the discretion of the contractor.
- Stockpile locations will need to be finalized during construction for large woody debris, reclamation materials, and soil that is not selected for dyke construction.
- The alignment and configuration of local drainage works will need to be finalized during construction.

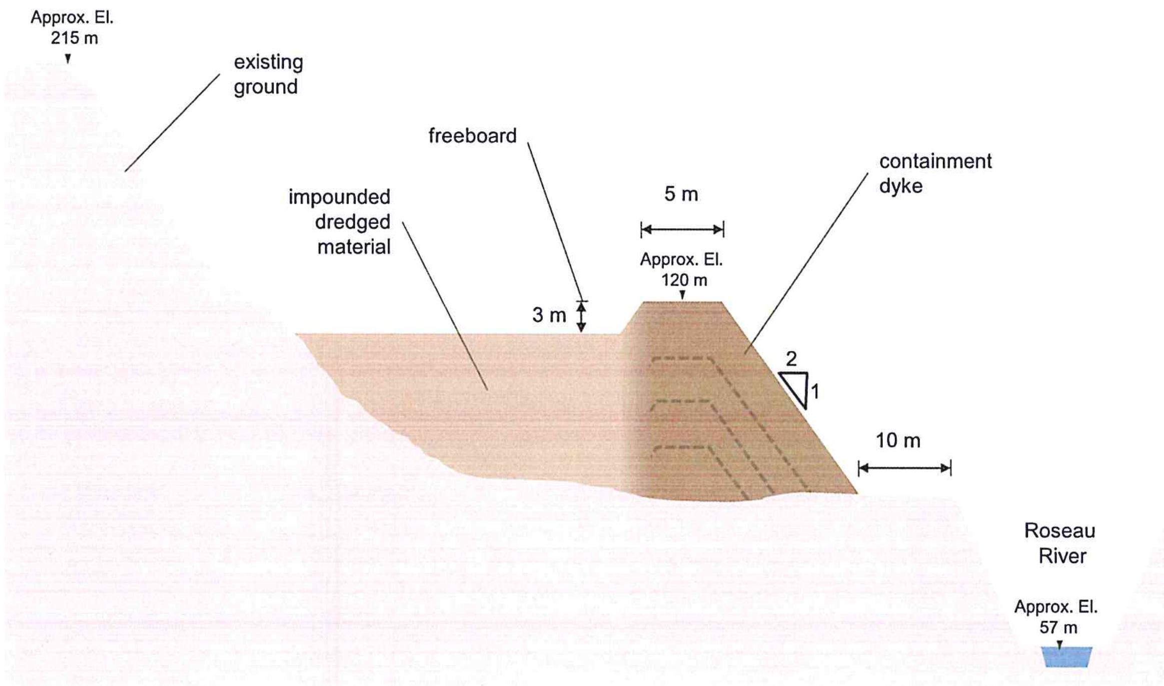



*Figure 27: SDA Typical Cross-Section*

**Table 6: SDA Containment Capacity**

| Dyke height [m] | Containment dyke coarse material [m$^3$] | Impounded fine and coarse material [m$^3$] | Total sediment volume [m$^3$] | Required freeboard [m] |
|---|---|---|---|---|
| 11.5 (starter) | 46,400 | 70,300 | 116,700 | 3 |
| 16.5 | 102,400 | 172,900 | 275,300 | 3 |
| 21.5 | 164,500 | 294,600 | 459,100 | 3 |
| 26.5 | 243,100 | 471,000 | 714,000 | 2 |
| 31.5 | 340,300 | 665,500 | 1,005,800 | 2 |
| 35 | 419,800 | 844,200 | 1,264,000 | 2 |
| *40* | *458,000* | *1,094,000* | *1,552,000* | *2* |
| *50 (ultimate)* | *534,000* | *1,594,000* | *2,128,000* | *3* |

## 7.5 Dredging Priorities

The dredging priority is to daylight the lower intake port, and to maintain the lower intake port. When the lower intake port is operable, dredging can proceed to other areas of the reservoir. The dredging priorities are:

- Zone 1 near the lower intake port should be dredged first, and also prioritized whenever the lower intake port becomes affected by sediment. Zone 1 sediment is expected to be clayey organic silt. Zone 1 should be dredged to 78 m (above sea level) within 100 m of the intake, with additional dredging as needed to provide a stable reservoir bottom. To daylight both the lower intake port and the low level outlet the amount of dredging in Zone 1 may be up to 80,000 m$^3$. Subsequent emergency daylighting of the lower intake port may require about 21 days removing about 40,000 m$^3$, depending on the shift lengths of the operating staff.

- Zone 2 near the sediment beach face can be prioritized whenever Zone 1 is not a priority. Zone 2 dredging should focus on the sediment within 3 m of the surface, and should maintain slopes to less than 10% for safety purposes. Sediment in this zone is expected to be gravelly sand with less than 5% fines.
- When WASCO arranges to rehabilitate the low level outlet for riparian flow the dredging operations will be moved to above the upstream portal of the diversion tunnel and the sediment will be dredged down to elevation 77 m around the existing intake valve for the low level outlet. The low level outlet is situated at elevation 78 m.

Dredging priorities are illustrated on Figure 28.

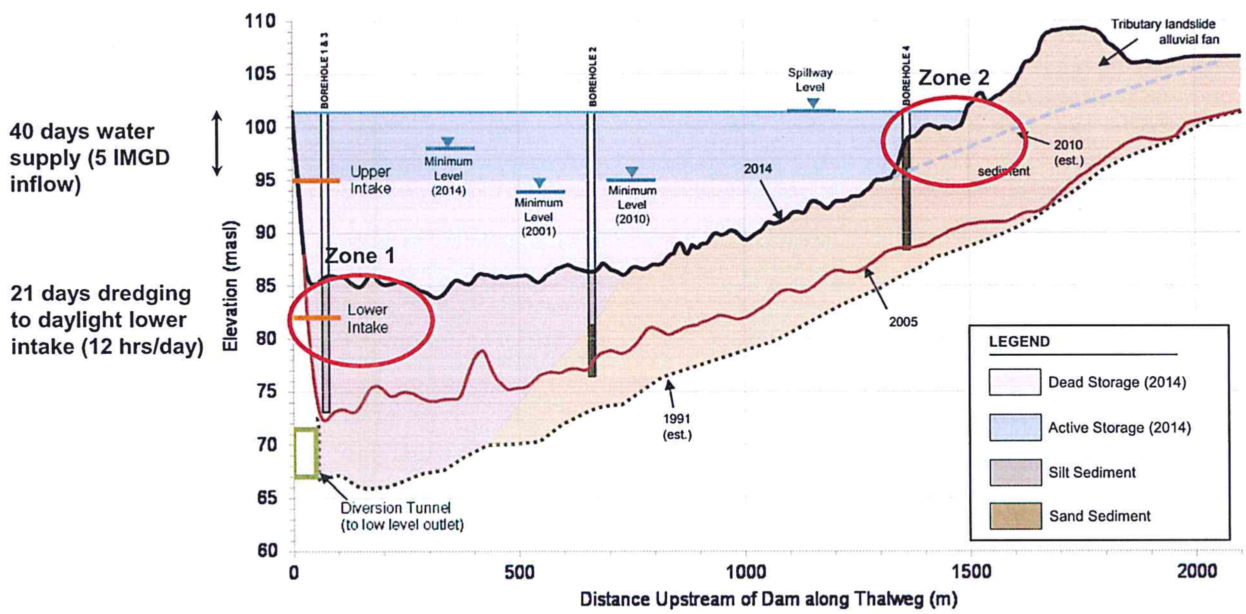



*Figure 28: Dredging Zones*

## 7.6 Water Supply Protection during Dredging

The drinking water quality from the JCD will be protected during the project by the following two methods:

- A hydrocarbon containment boom will be installed near the spillway, and other standard safety measures will be implemented according to an approved plan prepared by the contractor and approved by WASCO or by their representative.
- A silt curtain will be installed near the upper intake to control turbidity (when dredging within the vicinity of the dam), or an approved equivalent suggested by the contractor.
- Coagulant chemical stockpiles will be maintained at the WTP, as a contingency measure if some water from JCD has relatively high turbidity. WASCO currently maintains a stockpile of these chemicals. WASCO will need to ensure that the stockpile is maintained during dredging.

## 7.7 Water Quality Standards

### Reservoir Water Quality at the Intake

The contractor will be required to control the intake water quality, spillway releases, and SDA releases as a condition of the contract. Operations will be stopped and additional intervention may be needed if the standards are not met. Turbidity levels not to exceed 250 NTU are proposed for intake water to the Water Treatment Plant.

### Downstream Water Quality along Roseau River

It is recommended that turbidity levels be measured about 100 m downstream of the proposed SDA outfall location. Baseline samples should start prior to construction and dredging activities. Sampling should also occur on a weekly basis during construction. Work should be stopped if downstream turbidity exceeds the 5% exceedance level (i.e. 95% percentile), based on measured turbidity at the water treatment plant from 2011 to 2014. Contingency measures may be implemented as necessary until turbidity levels are compliant. Further details regarding monitoring requirements are reported as part of the Environmental and Social Management Plan (ESMP), provided within the Environmental and Social Impact Assessment (ESIA).

## 7.8 Roseau River Monitoring

Downstream water quality monitoring along the Roseau River will be implemented, in addition to regular monitoring of the water supply by WASCO.

Details of the required environmental monitoring to be undertaken are provided in the ESMP.

## 7.9 Land Purchase Requirements

Land purchase requirements are listed in Appendix F for private lands in the vicinity of the SDA.

## 7.10 Pump House Geohazard Protection

The existing pump house was damaged during Tomas by flying large woody debris (LWD) near the spillway, and by sediment accumulation as a result of a local landslide. These conditions are illustrated on Figure 29. The pump house should be protected by constructing a typical L-shaped wave wall along 3 sides of the pump house: along the river side, along the dam side, and along the pump house building. The wave wall is intended to deflect landslide sediment and debris from the spillway.

*Figure 29: Pump House Conditions after Hurricane Tomas (Macro Socio-Economic and Environmental Assessment of the Damage and Losses Caused by Hurricane Tomas: A Geo-environmental Disaster" February 2011).*

## 7.11 Temporary Intake as Short-term Contingency

Active storage capacity of Roseau Reservoir may need to be increased in the short-term if the dredging operation requires one or more years to be mobilized. The improvements likely consist of an additional temporary intake near 88.5 m to access reservoir water below the 95 m upper intake port. The temporary intake configuration should be selected in consultation with WASCO. One option would be to utilize the "future" intake shown on the dam construction drawings at 88.5 m (See drawing PA-2644-567). This short-term contingency will not restore the water supply to a sustainable reliability level, but will reduce the risk of a severe water supply failure.

The tee for the "future" intake is shown as the same type installed for the existing intake but with a blind flange. The new intake would allow access to the reservoir water between 95 m and 88.5 m. The installation would require the removal of the blind flange and the installation of a 600 mm lug-type butterfly valve with hand actuator as shown on the drawings. The installation would also require an intake screen mounted to the valve similar to the Johnson Model S-54 also shown on the drawings. The one drawback to this installation is that there is no indication on the drawings if there was a stub from the air line to attach to the additional screen. This would leave this screen without any backwash capability. The drawings indicate that there were two 168 mm diameter galvanized lines installed, one for each screen, and there was no spare line indicated. However, the drawings also show that a spare air outlet on the air tank is available to install another line. This would need separate anchoring to the face of the dam slope as the existing anchors do not have room for an additional line.

## 7.12 Large Woody Debris Removal

There is some woody debris that has settled with the sediment in the reservoir. This is assumed to be trees and tree branches which were washed into the reservoir or brought down with the landslides around the reservoir during Hurricane Tomas. Typically, woody debris floats for some time and is blown by the prevailing winds to the down-wind areas of the reservoir before it becomes waterlogged and sinks. Consequently, most of the woody debris is expected to be on the surface of the settled sediment, but some of the debris may be mixed in with the sediment.

A sub-surface seismic survey to locate the woody debris was carried out in 2015 and the report presented in June 2015 (see Appendix Q). The survey identified 130 objects greater than 1m on the surface of the sediment, the majority of which are interpreted as being logs, full trees, root balls, branches or stumps. These objects are concentrated close to the shore of the reservoir, at the toes of landslides and at the mouths of some of the tributaries that flow into the reservoir. The seismic survey methods were not able to identify woody debris buried in the sediment, however, as most of the debris is associated with landslides, the buried debris is expected to be close to the toes of the landslides and not distributed around the reservoir.

Suction dredges, even ones with cutter heads, are not capable of operating where there is a significant amount of woody debris, so it will be necessary to remove some of the debris before dredging. It may be more cost effective to not dredge some corners of the reservoir where there are high concentrations of woody debris.

The woody debris removal can be carried out during the dry season so that it does not interfere with the dredging operations. The "means and methods" of debris removal can be left to the contractor but the operation will likely require divers to attach cables to the underwater debris with winches at the boat ramp to haul the debris to the shore. It may be necessary to attach flotation devices (such as inflatable air bags) to the debris to avoid disturbing the sediment and affecting the water quality.

At the stakeholders' meeting, several participants indicated that the local residents could utilize the debris as a source for charcoal fuel. Therefore, the large woody debris (LWD) will be hauled by truck to a stockpile location that is accessible to local residents. The LWD stockpile is anticipated to be located along the WASCO road near the top of the ridge overlooking Millet.

## 7.13 Riparian Outlet (Low Level Outlet)

WASCO can sustainably release up to 7 L/s through the Riparian Outlet without eroding the water supply reliability from JCD, after other de-silting is completed. However, the Sediment Disposal Area (SDA) is expected to release between 30 L/s during dredging operations and 10 L/s at other times of the year (e.g. drought). These estimates are based on water balance analysis using 30 years of historical data whereby the release does not trigger additional water rationing.

Restoration of the upstream inlet for the Riparian Outlet will be possible after initial de-silting near the lower intake (water supply) port. The inlet is situated at 78 m at the construction diversion tunnel. Dredging will restore the drain access by dredging to a planned elevation of 77 m (above sea level), which should daylight the inlet for the Riparian Outlet. Any releases will likely be turbid water. The turbid water releases can be mitigated by further local dredging to about 74 m, but this requires additional dredging and disposal of silt.

Additional measures may also be required to restore the Riparian Outlet, depending on the results of an operations test by WASCO after dredging near the inlet. Restoration of the Riparian Outlet will need to be considered with other WASCO planning initiatives such as hydropower development.

## 7.14 Emergency Water Sources

Water supply reliability is expected to be improved significantly by removing reservoir sediment near the intake. Removal of sediment from the lower intake port is expected to reduce the future frequency of water rationing during the dry season. Currently, water rationing is expected to be required 2 out of every 3 years. Rationing would only be required once every 5 to 10 years on average after sediment is removed from around the lower intake port. This level of water supply reliability, about 87%, does not meet the selected target reliability of 90%. Emergency water sources will be required to meet the 90% reliability target, assuming that the current drought-frequent climate trend persists. The emergency sources are the Vanard intake and the Ravine Poisson intake, plus operation of the Cul-de-Sac reservoir as a standpipe water source. They are expected to increase the reliability equivalent to water rationing once every 10 years.

The residual vulnerability of Saint Lucia water supply will be due to the possibility of a drought condition similar to 2001. This drought was assessed as a 100-year event, but conservatively assumed to be a 30-year event for the purpose of this plan. Recurrence of a 2001 drought would result in a water supply failure despite the proposed sediment removal, because the current water abstraction rate is much greater than it was in 2001. The current water abstraction is near the design capacity of 10 IMGD.

The following emergency water source improvements are recommended for the Ravine Poisson intake, the Vanard intake, and the Cul-de-Sac Reservoir at Deglos.

### Ravine Poisson Intake

The Ravine Poisson intake is susceptible to siltation. The intake is a wet well on the bank of the river next to a concrete weir. Water flow is restricted from flowing into the wet well due to the sand and gravel build-up behind the weir. A properly constructed perforated pipe gallery could improve the reliability of the intake and reduce the maintenance requirements by allowing sediment to accumulate upstream of the weir. An air backwash system would also be required.

### Vanard Intake

The Vanard intake is also subject to siltation, but there are presently no permanent structures where silt can accumulate, as the on-site weir was a temporary sand bag and gabion structure. The recommended solution is similar to the Ravine Poisson intake. A perforated pipe gallery would be buried with larger rock along the bed of the river. An Aquadam portable bladder would be purchased and installed during an emergency to impound any surface water and improve the water abstraction rates. The Aquadam is expected to be required once every 2 years for about 2 months on average. At other times of the year, the river would be free flowing.

The Aquadam solution is recommended ahead of a permanent dam due to the local river conditions, which are within a relatively wide valley that is prone to flooding. Any dam would be at risk of trapping sediment and allowing the river to be diverted around the dam. The intake would then be stranded.

### Cul-de-Sac (Deglos) Off-Channel Reservoir

The potential off-channel reservoir (OCR) at the unused Cul-de-Sac (Deglos) facility is expected to provide additional resiliency against extreme drought conditions. It will not significantly improve the water supply reliability, but it may lessen the impact of a water supply failure. The Cul-de-Sac OCR requires a repair of the spillway and pond liner.

The Cul-de-Sac (Deglos) off-channel reservoir improvement is expected to be operated during emergencies as a standpipe water supply. The reservoir water would be treated on-site with a portable water treatment plant.

## 7.15 Traffic Management Plan

The Traffic Management Plan will consist of the following conditions along local roads:

- Heavy equipment use along Millet Road will be limited to hours between 9 am and 2:30 pm on Monday, Tuesday, and Wednesday unless otherwise approved by the Millet Development Committee.
- Maximum speed limit of 30 km/hr along Millet Road and the WASCO access road.
- Traffic control signage and flag men near the Millet School and Health Centre during heavy equipment use.
- Vehicle inspections prior to initial use to ensure vehicles are in sound working order, plus additional inspections at least once per month during regular use.
- Use guide vehicles for convoys of heavy equipment.
- Inspect the road prior to hauling any long vehicles through Millet, and arrange for additional traffic controls or road improvements as needed.
- Coordinate hauling periods and traffic controls with local police.

The traffic management plan will be further refined as needed in consultation with the contractor.

## 7.16 Dam Safety Inspections and Reviews

WASCO should arrange for regular dam safety inspections and reviews for both the JCD and the new SDA containment dyke. The inspections should include: (1) weekly inspections by the resident staff at the pump house at the dam; and (2) Dam Safety Review every 5 years.

The weekly inspections should involve a senior member of staff walking over of the full length of the crest of the embankment dam, the bridge over the spillway, and the downstream toes on the left and right abutments. The inspection should culminate in filling out a check sheet to record any signs of slumping or settlement, signs of cracking in the upstream concrete facing or in the spillway, signs of differential movement at the contraction joints of the parapet wall and the spillway slab, and any other signs of distress, along with routine maintenance recommendations. The check sheet should be submitted to the responsible WASCO engineer for review, action (if necessary) and filing.

A full Dam Safety Review should be carried out at no more than 5-year intervals by a dam engineer who has at least 10 years of experience in the design, construction, and monitoring of embankment dams. The Dam Safety Review should be conducted in accordance with international dam safety standards (e.g. Canadian Dam Association – Dam Safety Guidelines, 2007).

## 7.17 Dam Instrumentation Recommendations

See Appendix N.

## 7.18 Extreme Weather Management Plan

The Extreme Weather Management Plan for JCD is provided in Appendix M.

## 7.19 Source Water Protection Plan

A source water protection plan is needed to maintain the natural tropical rainforest upstream of JCD, as a strategy for sustaining the quantity and quality of the water source. The plan restricts upstream development to prevent contamination of the water source, and the plan defines measures for minimizing the sediment yield from landslides. Details of the plan will continue to be developed collaboratively with the Department of Forestry. It is assumed that Forestry staff will implement the plan, with support from WASCO.

The overall objectives for the plan are:

- Zero human disturbance within the watershed upstream of JCD;
- To stabilize disturbed soils where possible; and
- To utilize the upstream sediment beach as an efficient sediment trap.

The source water protection plan consists of the following:

- Forest protection:
  - Collaborate with Saint Lucia police drug squad to enforce forest protection measures against illegal development.
- Beach Re-vegetation:
  - Re-vegetate the sediment beach by seeding and with shrubs. No re-vegetation within 500 m of the beach face. Seed mixes to be selected by Forestry. Shrubs to be hibiscus malvaceae or equivalent approved by Forestry.
  - No re-vegetation with trees along the sediment beach.
  - No check dams or equivalent temporary structures to be used along the landslides.
- Landslide stabilization
  - Re-vegetate 3 landslides per year by seeding and with shrubs, but not with trees. Seed mixes to be selected by Forestry. Shrubs to be hibiscus malvaceae or equivalent as approved by Forestry.
  - No check dams or equivalent temporary structures to be used along the landslides.

- Monitoring:
  - Interpret the canopy cover for illegal development and landslide formation each year.
  - Site reconnaissance each year to selected locations and documentation of landslide conditions by geo-referenced photos.
  - Document re-vegetation by geo-referenced photos, and other standard Forestry inspection measures.
  - Correlate potential landslide triggers, based on a GIS comparison of soils, canopy cover, and existing landslide locations. Mapping sources consist of existing soil maps, and imagery as provided by the Golder UAV survey.
- Data purchases:
  - Purchase updated satellite imagery every year as the basis for monitoring illegal development and progression of landslides.
- Equipment purchases:
  - 2 cameras equipped with GPS to geo-reference the location of photos taken within the catchment.
  - 5 pairs of snake-resistant outer wear.
  - 2 backpack or handheld seed broadcast sprayers.

The existing sediment beach is an important component of the source water protection plan, because it is an efficient sediment trap. The beach sediment may eventually be dredged, depending on the timing of future sedimentation events. In the meantime, the sediment beach trap efficiency may be 50% or more for new sediment. The beach is an efficient trap because it has a relatively low gradient that is less than the natural channel prior to construction of the dam. The beach will become a better trap as additional sediment accumulates and further reduces the beach gradient. Beach development is expected to be episodic, in that some flood events may erode sediment while other events deposit sediment over time. Overall, however, the size and extent of the beach is expected to increase over time as sediment gradually accumulates.

The source water protection plan recommends two aspects that may be surprising. First, the plan restricts the planting of trees along the landslides and along the sediment beach. While trees may eventually regenerate naturally, trees should not be encouraged in areas where they may be delivered to the reservoir. This is especially true along the sediment beach where trees may be uprooted during a large flood event. Secondly, check dams should be avoided. Any check dams in the catchment are likely to be constructed as temporary structures using local materials with hand labour. These structures will eventually fail and potentially result in a greater debris flow than might otherwise occur.

## 7.20 Sediment Re-use

Sediment re-use would extend the life of the SDA by several years, depending on the rate of re-use. For example, without any sediment re-use, a dredging rate of about 100,000 $m^3$ per year would result in a life span of about 18 years. Re-use after the second dredging season, at a rate of 50,000 $m^3$ per year, could extend the life of the SDA to about 32 years and contribute additional benefits associated with utilizing the sand as an engineering material.

Overall, 70% of the reservoir sediment deposit is expected to consist of sand. Some of this sand may be suitable as an engineering material, depending on the relative minority portion of silt. Up to 50% of the sediment may consist of well-sorted sand with less than 5% fines, based on the location of the sediment and the available borehole information from field investigations. Some of this sand will be needed to raise the containment dyke. The remaining sand could be available for re-use. Initial indications, therefore, are that up to 50% of the reservoir sediment may be available for re-use.

It was assumed that WASCO or others would propose a business plan for sediment re-use. The demand for sand aggregate on Saint Lucia has not been evaluated in detail, but it is known that sand is currently imported to the island and that stakeholders have expressed a further desire to utilize some of the sand for local initiatives such as new sports fields. It may be possible to donate a portion of the sand for public works projects such as new sports fields. Depending on the demand for sand, the remaining aggregate resource may be sold privately or allocated as part of a gravel mining concession.

Sand is normally considered to be a valued resource in most countries where this resource is managed and regulated similar to other mining industries, including royalties to the government. Similar gravel resource mining regulations do not currently exist in Saint Lucia. Such regulations would likely discourage any "sterilizing" of the resource by discharging or depositing the sediment to locations where it cannot be recovered, such as releasing the sediment to the downstream Roseau River.

## 7.21 Potential Future Road Access from Dame de Traversay

Sediment re-use may be possible from the SDA after the second year of dredging. A suitable haul road does not currently exist. Any sediment re-use at off-site locations will likely require a new haul road through Dame de Traversay plus road improvements through Millet. The road would cross the Millet River at the existing bridge (with upgrades) and follow existing road and trail alignments to the existing WASCO access road as shown on Figure 30. The new road length is expected to be 1,840 m, designed for haul traffic. Additional road improvements will also be needed at two road bends in Millet. Provisions will be needed for long-term road maintenance.

The detailed design and environmental and socio-economic impacts of a new access road have not been included in this report and will need to be further developed if a business case is developed.

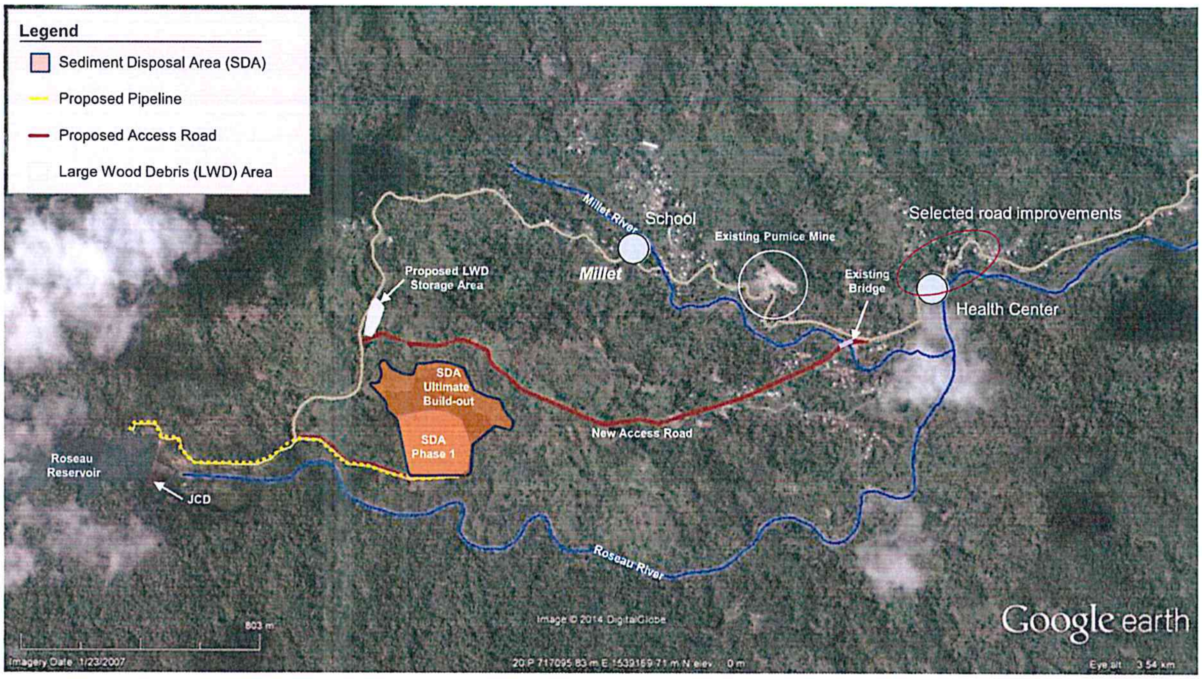



*Figure 30: Potential New Road Access to the Sediment Deposit Area*

# 8.0 IMPLEMENTATION PLAN

## 8.1 Dredging Contract Options

WASCO has the flexibility of dredging more quickly or more slowly, provided that the lower intake port is daylighted and restored. Three possible contracting options could be considered for the work. These include:

- **Option 1 - All Contractor Work:** All dredging, transportation (piping and pumping), deposition area construction and woody debris removal could be done by a contractor selected through international bidding. Dredging can only be done for 6 months each year during the high flow season, so an international contractor would need to demobilize and remobilize several times as the work will take several years to complete. Consequently, this will likely be the highest cost option. In addition, it would not provide the equipment for the removal of additional sediment in the event of future major storms.

- **Option 2 – Partial Contractor Work:** Procurement and installation of all the equipment and the initial dredging, woody debris removal and starter dyke construction could be done by a contractor selected through international bidding. WASCO could then take ownership of all the equipment, pipeline, etc., and a local contractor could be contracted to continue the dredging operations. Alternatively, WASCO's internal forces, possibly with assistance from specialist consultants could take over the equipment and continue the dredging operations. With either of these alternatives the equipment would be in place for use in the event of future major storms.

- **Option 3 – WASCO Work with Specialist Input:** All the equipment could be purchased and installed and all dredging operations could be carried out by WASCO with technical assistance from specialist consultants or contractors. This will require WASCO to develop a specialist group who can manage the operations. Some of the work (such as pipeline installation, woody debris removal and containment dyke construction) could be done by local contractors. The equipment could be purchased by international bid.

Each of these options has advantages and disadvantages and requires different actions, although Golder recommends Option 2 as the most cost-effective and beneficial to the local economy. Option 3 would also benefit the local economy, but it would require WASCO to operate outside its core business of supplying potable water. The selection of a preferred contracting option should be done by WASCO in consultation with the lending agency.

The selected dredging contractor should be experienced with suction dredging, complete with references. Contractor pre-qualification information is provided in Appendix G.

## 8.2 Recommended Work Packages

The following work packages are recommended for WASCO to contract the various portions of work associated with the Rehabilitation Plan, assuming that WASCO and the funding agency select the equivalent of Option 2 above.

### Contract 1 - Dredging Contractor

A specialist dredging contractor will be responsible to purchase, ship, install, test, and to initially operate the dredging equipment and to remove the woody debris that would obstruct dredging operations. The dredging contractor would also be responsible for constructing the other required infrastructure, including the pipeline and sediment disposal area. The sediment disposal area will require earthworks and installation of civil structure for the slurry spigotting, water decanting, emergency spillway, local drainage works, and erosion and sediment control as needed to comply with the selected water quality standards.

### Contract 2 – Long-Term Dredging Operations

The specialist dredging contractor is expected to train the dredging operations contractor, and subsequently to hand over the site responsibility to long-term dredging operations (contractor) with oversight from WASCO and the Project Engineer. The operations contractor will operate the dredge system, including required maintenance and remove the woody debris that would obstruct dredging operations. The contractor will also maintain the ancillary systems, including the sediment disposal area.

### Contract 3 - Engineering Support for Dredging

The Project Engineer is expected to provide engineering support for the dredging program, including oversight of both the specialist dredging contractor and the dredging operations contractor and especially during the transition period from one contractor to another. It is assumed that Golder Associates Ltd. and partners will provide engineering support as the engineer-of-record for the design.

### Contract 4 - Emergency Water Sources

Improvements at emergency water sources such as the river intakes (Vanard and Ravine Poisson) and the Cul-de-Sac Reservoir are expected to be constructed by additional contractors at the discretion and direction of WASCO.

### JCD Instrumentation Repairs

WASCO is expected to contract the repair work for dam instrumentation separately.

### Pump House Protection Measures

WASCO is expected to contract the construction of an L-shaped wave wall separately. The wave wall should be designed for water impact loads.

### Sediment Re-Use

WASCO is expected to consider sediment re-use business plans by others, and may issue a concession for any aggregate resource that may be salvaged from the sediment.

### WASCO Reservoir De-Silting Manager

A full-time manager may need to be added to the staff of WASCO, depending on existing staff capacity. The manager would be responsible for administering the contracts, and to liaise with stakeholders and regulators. The manager would also be responsible for land purchases, large woody debris management, instrumentation repairs at John Compton Dam, and future sediment re-use plans.

## 8.3 Contract 1 – Initial Dredging

Contract 1, for initial dredging activities, is expected to be tendered in 2015. The tender package for Contract 1 is located in Appendix H.

Contract 1 includes:

- Procurement of all dredging equipment, barge, booster pump, ancillary equipment, site office, construction site facilities, supplies and maintenance equipment. This equipment will become the property of WASCO at the end of the contract. Includes shipping, importing, hauling, assembling, crane rental (for equipment assembly), and installing all equipment in place.
- Procuring and installing all equipment for removing woody debris.
- Procuring and installing the slurry pipeline from the dam to the deposition site and from the dam to the dredge.
- Procuring all construction equipment for construction of the dykes in the deposition area. This equipment will become the property of WASCO at the end of the contract.
- Constructing the starter dyke and stage 1 divider dyke using local soils.
- Constructing the decant pipe and riser for the first 2 stages of dredging and deposition.
- Removing woody debris from the sediment in the area to be dredged.
- Dredging and pumping the fine sediment from around the water supply lower intake and then the coarse sediment from the upper end of the reservoir.
- Drilling and test pitting to investigate the foundation conditions for future raises of the containment dyke.
- Construct the first raise (Stage 2) of the containment dyke.
- Reinstating the lower intake port.
- Handing over the dredging operations and equipment to WASCO or a WASCO nominated contractor, including training operators who will take over dredging and deposition operations at the end of Contract 1.

## 8.4 Contract 2 – Long-term Dredging Operations

Contract 2, for long-term dredging operations, is expected to be tendered in 2016. The tender package for Contract 2 is located in Appendix I.

Contract 2 includes:

- Taking over the equipment, dredging operations and dyke construction from Contract 1.
- Continuing dredging, sediment removal, woody debris removal, dyke raising and sediment deposition management to remove all sediment from the active storage areas in the reservoir.
- Completing the construction of the deposition dykes when the deposition area is full, including constructing an emergency spillway, installing permanent erosion protection measures and grading the surface of the deposition area so that there is no standing water.

At this time, the technical requirements of Contract 1 are clear and the technical details have been specified in the drawings and technical specifications. However, the requirements for Contract 2 cannot be fully defined at this time as they will depend on the potential re-use or re-sale of the coarse sediment as sand for local construction. This will determine what volume of sediment has to be contained in the deposition area and the final height of the containment dyke. Consequently, the tender documents for Contract 2 will need to be reviewed and revised (if necessary) when construction in Contract 1 is well advanced.

## 8.5 Contract 3 - Engineering Support during Dredging

The design, construction and operations for this project are unusual. There are very few projects that include dredging sediment from a water supply reservoir, pumping the sediment to a disposal area, removing woody debris from the bottom of the reservoir, managing the sediment disposal so that the sediment can be used for dyke construction or for sale as sand, and raising dykes in increments. None of these exercises can be precisely defined and designed in complete detail, as one should be able to do for the design and construction of a hospital or a water treatment plant.

The dyke will ultimately be upwards of 50 m high and will retain up to 2 million $m^3$ of sediment. Consequently, the dyke could pose significant risks to the population downstream unless the construction is closely monitored and the design is adapted, if necessary, to suit the in-situ materials and foundation conditions as they are exposed during construction. The dyke is, in reality, a large embankment dam. The philosophy recommended by international dam organizations is that "the design of a dam is not complete until the last cubic metre of material is placed". Consequently, it will be necessary to have qualified engineers on site throughout construction to direct the dredging and deposition operations and to oversee the construction of the dykes. In particular, the site engineers will be required to direct where to dredge in the reservoir to remove sediment from the intakes and to supply suitable sediment for dyke raising, to direct spigotting operations so that coarse sediment settles against the upstream face of the containment dyke, to determine the depth of foundation excavation and the suitability of the dyke foundation surface, and to determine the levels of the incremental raises of the decant ports and the dykes. In addition to these duties, the site engineer will be required to monitor and test the quality of the fill placement and general construction, to ensure that the contractor is complying with the specifications and to review payment certificates.

WASCO's internal engineering staff could provide these construction engineering services or they could employ a qualified engineering company to provide the services. We recommend that the construction engineering staff includes a full time geotechnical engineer or equivalent during all construction activities throughout Contract 1, testing technicians on an as-needed basis, full time administrative assistants, and senior dam and construction engineers to visit the site at strategic times. Full-time on-site supervision is necessary during construction activities for the first year of Contract 2 with regular visits to site throughout construction in subsequent years.

Contract 3 is expected to be executed in 2015 for the initial two years, and renewed every two to five years.

## 8.6 Contract 4 – Emergency Water Sources

Contract 4, for improvements at the emergency water sources, is expected to be managed by WASCO and executed in Q1 2015.

Detailed descriptions and specifications are provided in Appendix J for the recommended improvements at the emergency water sources: Ravine Poisson river intake; and Vanard river intake.

## 8.7 Tender Packages

### Contract Requirements

Contract procurement will be in accordance with the lending agency and WASCO requirements. The divisions of the contract will be based on the Caribbean Development Bank's standard contractual requirements to include the following sections:

- Section I – Instructions to Bidders.
- Section II – Bid Data Sheet.
- Section III – Evaluation Qualification Criteria.
- Section IV – Bidding Forms.
- Section V – Eligible Countries.

Golder does not have access to WASCO's requirements for all the contractual issues for items such as foreign currency requirements in the contract, bid security, bid bonds, performance bonds, schedules for bidding and for construction (which will depend on financial arrangements), bid evaluation criteria, payment procedure, retention and other details. These divisions of the contract documents will need to be prepared by WASCO. However, we have prepared the Bill of Quantities.

### General Conditions of Contract

WASCO's construction contracts will be carried out under the FIDIC General Conditions of Contract. The General Conditions have been prepared as appropriate for the sediment removal contracts. However, there are outstanding items to be addressed by WASCO, such as insurance requirements and the requirements for a Disputes Board. Also, the downloaded document from FIDIC states that these documents are "*For participating development bank financed contract use only*". No reproduction of this document is permitted without prior permission in writing from FIDIC. To request such permission, please contact: FIDIC, Case Postale 311, CH-1215 Geneva, 15, Switzerland; Tel. +41 22 799 49 00; Fax +41 22 799 49 01; E-mail:fidic@fidic.org." WASCO should seek approval to use these General Conditions of Contract directly from FIDIC.

### Technical Specifications

Technical specifications have been prepared in a standard format for Contract 1 and 2. This includes 15 Divisions of the technical specifications to cover the various aspects of construction, from dredging to sediment management to dyke construction to diversion and more. Each division includes details of the measurement and payment for each item in the contract.

### Drawings

Contract 1 has 16 drawings (Appendix H) and Contract 2 has 14 drawings (Appendix I).

### Engineer's Estimate

The Engineer's Estimates for Contracts 1, 2, 3, and 4 have been included in Appendix E. The actual tendered costs will depend on the bids. The estimates have been developed using the construction quantities in the Bill of Quantities, which are included in Section IV – Bidding Forms of the CDB Contract Forms. The quantities are considered to be accurate within the limits of the topographic survey, except for the estimates for removal of woody debris and depth of foundation excavation for the dykes which are based on site observations. Accurate estimates for these items can be calculated when the planned investigations are completed.

## 8.8 Construction Sequence

The details of the implementation plan will, to a certain extent, depend on the contracting option selected. In general, the implementation plan will involve the following steps:

1) Develop the Vanard intake as an emergency water source by purchasing an aqua-dam for emergency use, and by removing the existing dam remnants; install recommended electrical/mechanical equipment (design details TBD).

2) Install a gallery intake at the Ravine Poisson intake.

3) Develop the Cul-de-Sac off-channel reservoir as an emergency water source (design details to be determined by WASCO).

4) Review the underwater seismic survey of reservoir to identify concentrations of woody debris. Winch large trees out of the reservoir and stockpile for the local residents to use for charcoal fuel.

5) Clear the old laydown area, plus a portion of the valley wall. Salvage the wood and mulch the small vegetation.

6) Construct the sediment containment dyke and dewatering system, starting with the starter dyke.

7) Procure dredge, barge, pipes, and service equipment and have it shipped to Saint Lucia. Haul in dredge equipment in pieces up the Millet Road.

8) Install a sit curtain or approved equivalent near the upper intake.

9) Install the dredge and pipeline.

10) Dredge the sediment (in the wet season, when the reservoir is full), starting with removal of sediment around the lower intake, then moving to an upstream deposit of coarse sediment which can be used construct the containment dyke. In this plan, the starter dyke will be constructed using soil in the laydown area so there will be no large scale hauling of sediment along the Millet Road.

11) Restore the lower intake port operations.

12) Dredge about 0.1 million $m^3$ during the wet season each year and manage (re-grade) the sediment every dry season.

## 8.9 Project Schedule

The project schedule should aggressively attempt to restore the lower intake port in 2015 as an ideal schedule. The resulting schedule may not be realistic, depending on funding sources. The tentative schedule is presented in Table 7.

**Table 7: Tentative (aggressive) Project Schedule**

| Milestone | 2015 Calendar Year | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | January | February | March | April | May | June | July | August | September | October | November | December |
| JCD Rehabilitation Plan (design) | ■ | ■ | ■ | | | | | | | | | |
| Extreme Weather Management Plan | | ■ | | | | | | | | | | |
| ESIA and ESMP | | ■ | | | | | | | | | | |
| Operations Manual | | | | ■ | | | | | | | | |
| Funding approval | | | ■ | | | | | | | | | |
| Contractor prequalification | | ■ | | | | | | | | | | |
| Land purchase | | | | ■ | ■ | | | | | | | |
| Tender | | | | ■ | ■ | | | | | | | |
| Contract award for dredging | | | | | | ■ | | | | | | |
| Contractor mobilization | | | | | | | ■ | | | | | |
| Improve local access road | | | | | | | | ■ | | | | |
| Clear old laydown area | | | | | | | | ■ | | | | |
| Install silt curtain at dam intake | | | | | | | | ■ | | | | |
| Dredge, pipeline installation | | | | | | | | ■ | | | | |
| Remove LWD from reservoir | | | | | | | | ■ | ■ | | | |
| Construct containment dyke, decant | | | | | | | | ■ | ■ | | | |
| Dredge commissioning | | | | | | | | | | ■ | | |
| Dredging | | | | | | | | | | ■ | ■ | ■ |
| Daylight lower intake port | | | | | | | | | | | ■ | |
| Restore lower intake port | | | | | | | | | | | | ■ |
| Emergency water sources | | ■ | | | | | | | | | | |

# 9.0 ENVIRONMENTAL SOCIO-ECONOMIC AND GENDER IMPACTS AND OPPORTUNITIES

## 9.1 Overview

This chapter summarizes the potential environmental and socio-economic impacts of the recommended John Compton Dam De-silting and Rehabilitation Plan, describes how the adverse environmental and socio-economic effects are mitigated where possible, and describes how potential employment opportunities or benefits were considered. Future sediment mining operations and associated works (e.g. new access road) are outside the scope of the assessment.

The first objective of an impact assessment is to document the baseline environmental and socio-economic land use conditions associated with the JCD de-silting and rehabilitation project. From the baseline conditions, potential adverse or beneficial effects from the Project were then assessed to develop plans to ensure potential adverse effects are managed. The baseline conditions and potential adverse effects have been presented in the Environmental and Socio-Economic Assessment (ESIA). All of the mitigation measures and monitoring requirements are detailed in full with additional guidance in an Environmental and Socio-Economic Management Plan (ESMP) that is appended to the ESIA. The ESMP is a guidance document for the Contractor to use in the development of a comprehensive, project specific, Environmental Protection Plan.

Within the ESIA each project activity that has a potential interaction with a valued environmental or socio-economic element is identified as positive or negative and given a significance rating. A significance rating system was developed to rate the level or severity of effects that are residual after the application of mitigation and monitoring. Overall, there were two moderately negative residual effects associated with environmental impacts of the Project from sedimentation of the downstream watercourse(s) and land clearing activities, to water quality and wildlife, respectively:

- Water releases will be monitored during construction to help prevent turbidity from exceeding a threshold value.
- The clearing associated with the project is in an area that is not considered to be critical habitat and is common within the immediate area and in the watershed. Each of the three sensitive or critical species that may be within the project footprint are tolerant of various habitat characteristics that can be met by other areas within the watershed. Also, the pre-construction survey will further reduce the potential for mortality or disturbance of wildlife, including these critical species.

Overall, it was concluded that adverse environmental effects associated with Project works (construction and dredging operations) are outweighed by the positive socio-economic effects from a reliable water supply. Once the lower intake at JCD is exposed and maintained the increase reliability in water supply will provide benefits to the majority of Saint Lucia residents on the north end of the island. This provides a significant positive effect to Saint Lucia residents and businesses, particularly tourism operations.

Refer to Appendix K for the full ESIA and the appended ESMP for details on the baseline conditions, impact assessment and mitigation and monitoring requirements for the JCD De-Silting and Rehabilitation project.

## 9.2 Mitigation Measures

The project is expected to include the following mitigation measures to manage the potential impacts:

- No sediment would be discharged to the downstream Roseau River. Water releases will be controlled to comply with selected turbidity limits.
- Disturbances will be isolated to areas that were previously disturbed near the dam, including the Old Laydown Area. Other de-silting options would likely disturb a larger area, require a longer pipeline, and impact land that is currently utilized for other purposes.
- The natural tropical forest upstream of JCD would remain inaccessible to development, by avoiding the construction of a new road access to the sediment beach deposits upstream of the reservoir.
- A pipeline to the Old Laydown Area will limit the haul traffic on Millet Road to a small number of trucks to haul in dredge and pipe equipment.
- Erosion and sediment control best management practices (BMPs).
- Water quality measures, including a silt curtain at the JCD intake, will be used to maintain the current quality of the potable water supply.
- Source water protection plan to maintain the undeveloped nature of the catchment area and to reclaim existing landslides.
- Traffic management plan to control time-of-day uses, traffic controls, dust suppression, road maintenance, etc.
- Bird nest survey and avoidance plan for the sediment deposit area (SDA) and other disturbed areas.
- The de-silting plan will likely focus on (permanent) local employment as part of long-term sediment management.
- Large woody debris (LWD) removed from the bottom of the reservoir will be deposited in a nearby dedicated storage area, to be accessible for re-use by local residents as a charcoal fuel source.
- The selected SDA location avoids valleys that are currently utilized for other uses such as subsistence farming managed by local women villagers in Millet. The selected Old Laydown Area was previously disturbed in the 1990s and is currently undeveloped.
- Sediment re-use to salvage sand and gravel for other beneficial economic uses after it has been deposited in the SDA, subject to the local economic limitations of a future business plan (outside the scope of this project).
- Releases from JCD will be unchanged, in that the reservoir will continue to spill uncontrolled when the reservoir level exceeds the spillway elevation, and there will continue to be a nominal amount of seepage through the dam.

## 9.3 Residual Impacts

The plan to dredge sediment to the Old Laydown Area represents the minimum possible environmental and socio-economic impacts for de-silting the reservoir. The remaining residual impacts (illustrated on Figure 31) are expected to consist of the following:

- There is a potential to disturb the breeding habitat of vulnerable and endangered bird species by clearing the selected sediment deposit area (SDA) for long-term sediment management. Breeding birds, including but not limited to species such as the Saint Lucia Amazon parrot and Saint Lucia black finch, may lose about 15 ha of secondary growth and montane rainforest from the SDA. These areas are all previously disturbed, including the SDA, which was originally cleared for use as a laydown area when the dam was constructed in the 1990s. At the same time, this impact is expected to be less than all other options to develop the SDA at a larger location that is further away from the JCD.
- Invasive species could be introduced or spread as a result of construction activities, including vegetation clearing.
- Nuisance noise and air quality impacts within the local area where project operations are expected to occur near the JCD.
- The landslide stabilization program is expected to have uncertain results at restoring the catchment vegetation at landslide locations, but may reduce the sediment supply to the reservoir.
- Flow along the downstream Roseau River will be similar to current conditions when WASCO abstracts 10 IMGD at JCD, but the flow during drought conditions will be increased by about 10 L/s as a result of SDA decant water releases. Roseau River flow is shown for several options on Figure 32, including a potential future dam raise.
- The water supply reliability will be less than 100%, but is expected to be within a manageable target that should avoid major water supply disruptions in all but severe drought events similar to 2001.

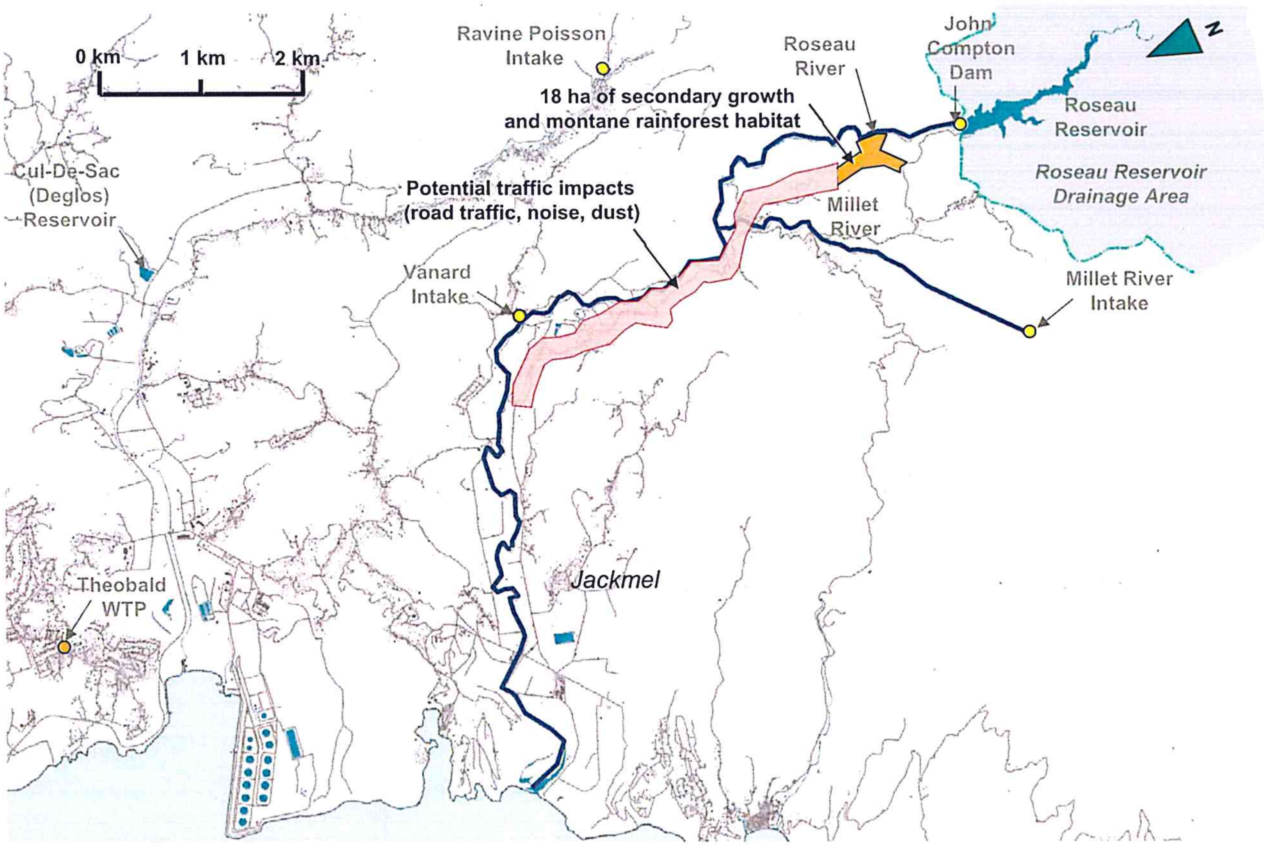



*Figure 31: Location of Expected Environmental Impacts*

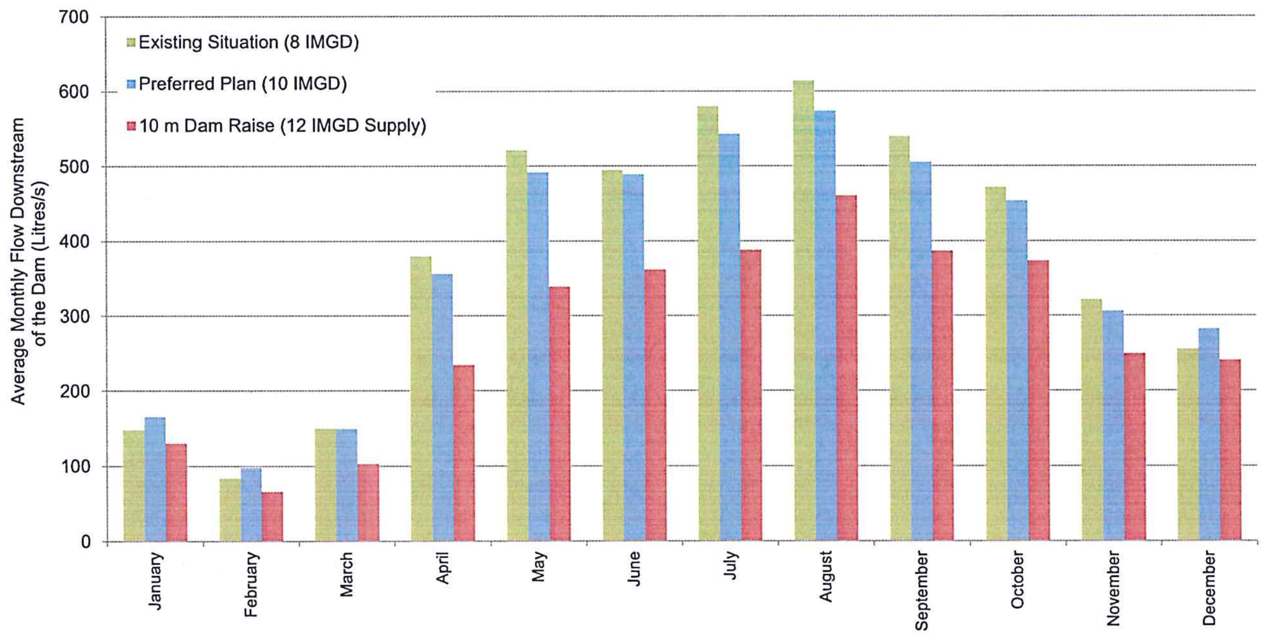



*Figure 32: Roseau River downstream of JCD, Average Flow for Selected Scenarios*

## 9.4 Expected Socio-Economic Benefits

The project is also expected to result in a number of socio-economic benefits that should be highlighted:

- Local employment is expected to be benefited by about 46 permanent jobs, due to direct employment of about 5 staff for the project plus indirect employment by supporting industry.
- Local residents will have access to a new source of charcoal fuel.
- Some of the sediment may be re-used as a construction material to develop sports fields and private properties. The relative economic benefit of sediment re-use will depend on a detailed business plan to be developed by others. It's likely that about 50,000 $m^3$ per year of sand may be available for re-use after the initial 2 years of operation, equivalent to a deposit with 4 feet thickness spread over 10 acres.
- The selected option to dredge, store, and potentially to re-use sediment from a location close to the dam, avoids environmental impacts of storing sediment at locations that are further from the dam and would require a much larger environmental footprint. The option also avoids discharging sediment to the downstream Roseau River, where the stakeholders have expressed firm concerns about the impacts of downstream releases.

A high-level summary of environmental and social considerations is provided in Table 8. The detailed Social and Gender Impact Assessment is provided in Appendix K. A more comprehensive assessment of project effects is provided by the ESIA in Appendix K.

Table 8: Environmental and Socio-Economic Issues and Opportunities

| Environmental or Socio-Economic Element | Interest | Project Activity | Potential Effect | Effect Pathway | Mitigation Strategy for Minimizing Impact |
|---|---|---|---|---|---|
| Water Supply | Sustained water supply | Sediment dredging | Reduced water quality due to excessive sediment levels | Sediment dredging in the vicinity of the reservoir intake leads to unacceptably high turbidity, and possible shut-down of the reservoir water supply | A silt curtain will be installed at the intake, a standard measure, to mitigate the potential elevated reservoir turbidity. Additional coagulant chemicals will also be stored at the Water Treatment Plant as a contingency measure |
| | Reduce future sediment loading in the reservoir | Rehabilitation and restoration activities in the upstream catchment areas | Minimize future risk of landslides | Future landslides may deliver additional sediment to the reservoir | Development of landslide stabilization program. Development of source water projection plan. |
| | Minimize sedimentation of downstream watercourses | Site preparation (clearing old lay down area, new road construction) and sediment storage | Loss of soil stabilizing vegetation within the disturbance footprint | Land clearing within the disturbance footprint | Erosion and sediment control BMPs |
| | | | Storage of silt and sand extracted from the reservoir | Runoff form storage piles entering the waterways | Sediment containment dyke and dewatering system |
| | | Upgrades / works associated with the Vanard and Ravine Poisson Intakes | Temporary increase in sedimentation within the disturbance footprint. | Disturbance of the riverbed during perforated pipe gallery installation and removal of existing dam at Vanard intake. | Erosion and sediment control BMPs.<br>Work will be conducted in the dry through temporary diversion of watercourse. |
| Vegetation and Wildlife | Maintain functional integrity of the natural vegetation types and wildlife habitat in the area | Site preparation (grading, clearing) | Direct loss of wildlife habitat and habitat connectivity/ corridor function | Loss of vegetation/disturbance of habitat during construction activities (e.g. laydown area) | Contain disturbance footprint to 18 ha (45 acres) lost habitat due to clearing of the sediment deposit area (previously disturbed site). Reclaim temporarily disturbed areas as soon as possible. |
| | Prevent unacceptable disturbance, displacement, or mortality of local wildlife | Site preparation (grading, clearing) | Displacement of wildlife and human-wildlife conflicts | Wildlife disturbance during construction/dredging activities due to noise effects | Avoid breeding windows for vulnerable or critical species to the greatest extents possible by dredging during the wet season. Conduct bird nest surveys prior to construction to develop avoidance strategies as needed. |
| | | | Disturbances to nesting birds | Disturbance due to construction activities (e.g. noise and light) | same as above |
| | | Hauling materials | Direct loss of wildlife due to human-wildlife conflicts | Truck traffic to transport materials may result in an increase in wildlife mortality rates on the transportation routes | Traffic management plan to minimize wildlife mortality from trucks traffic |
| | Maintain populations of vulnerable or critical species | Site preparation (grading, clearing) | Loss of vegetation/habitat for wildlife species that are considered vulnerable or endangered either nationally or internationally | Land clearing within construction footprint | Conduct bird nest surveys prior to construction to develop avoidance strategies as needed; avoid new disturbances during the dry season |
| Traffic | Maintain or improve air quality | Trucks hauling materials to and from Project site, operation of equipment with combustion engines, | Decrease in air quality for local communities | Use of trucks and other combustible engine equipment | Traffic management plan for dust suppression and road maintenance |
| | Minimize disturbance to local communities (e.g. noise, dust, traffic congestion) | Trucks hauling materials to and from Construction site. | Increased ambient noise equipment.<br>Increased dust from equipment operations.<br>Traffic congestion for regular traffic. | Use of local roads for hauling materials | Traffic management plan for:<br>■ Working during daylight hours to minimize noise disturbance.<br>■ Ensuring that trucks are fitted with functioning mufflers.<br>■ Minimizing truck movements on days of particularly high activity within local communities. |
| | Maintenance of road conditions | Trucks hauling materials to and from construction site. | Damage of existing roads. | Use of local roads for hauling materials | Traffic management plan identifying speed limits, vehicle inspections, road inspections, and the arrangement of road improvements as needed. |
| | Safety of local public using the road (i.e. pedestrians, other motorists). | Trucks hauling materials to and from Construction site. | Increased traffic / congestion leading to greater risk of accidents / collisions. | Use of local roads for hauling materials. | Traffic management plan to respect the activity of school children, and weekly activity when local produce is shipped to markets (Thursday and Friday), and travel to and from prayer and church (Saturday and Sunday). |

**Table 8: Environmental and Socio-Economic Issues and Opportunities**

| Environmental or Socio-Economic Element | Interest | Project Activity | Potential Effect | Effect Pathway | Mitigation Strategy for Minimizing Impact |
|---|---|---|---|---|---|
| Local Economy | Employment from Project construction and operations. | Initial on-site construction activities.<br>Truck Hauling.<br>On-going operations and maintenance activities. | It is estimated that approximately 46 people will be engaged in direct employment (by WASCO or by supporting industries), and a significant number of additional people will be engaged indirectly. | Construction and operations personnel will be required for:<br>■ Administration and de-silting activities on site.<br>■ Transportation and hauling activities.<br>■ Provision of ancillary activities such as catering, food and beverage, laundry and daily consumables. | Local employment will be maximized if WASCO chooses to develop internal resources for operating the project. The benefits will be based on direct employment and indirect employment. |
| | Indirect economic opportunities. | Removal of woody debris from the reservoir prior to dredging activities. | Availability of woody debris for pick-up and use by local communities. | Woody debris can be stored for the sustainable use of materials recovered from the Dam (e.g. for making charcoal). | Opportunity for local residents to re-use woody debris as a charcoal fuel source. Once removed from the reservoir, woody debris will be stored in an accessible and convenient location for pick-up by local community members. |
| | | Removal and storage of sediment removed from the reservoir. | Sediment re-use following dredging and storage. | Use of some of the dredged material by local communities (e.g. for playing fields or other land improvements). | Opportunity to develop a business case for long-term re-use of sediment dredged from the reservoir, in consultation with stakeholders.<br>The available sand resource is currently estimated to be about 50,000 $m^3$ per year after the initial 3 years of dredging. |

# 10.0 CLIMATE VULNERABILITY ASSESSMENT

A climate vulnerability assessment (CVA) is a specific requirement for funding under the European Investment Bank (EIB) CALC program. The following addresses these requirements, and documents the resiliency of the proposed JCD De-silting and Rehabilitation Plan under predicted changes in climate conditions.

The CVA evaluates the key infrastructure components of the project that may be vulnerable to climate change, describing the climate (recent historical and projected), and assesses the projected responses of the infrastructure to predicted climate changes.

## 10.1 Key Infrastructure

Previous accounts of extreme weather events (e.g. Hurricane Tomas and the Christmas Eve Trough) demonstrate that the current infrastructure is vulnerable to climate events. During Hurricane Tomas, JCD experienced local landslides along the access road and a major landslide that damaged a back-up generator and the pump house (ECLAC, 2011). It was also reported that the pipeline from the Millet storage facility also suffered damage, due principally to landslides and erosion. It was estimated that the dam outage from the damages caused by Hurricane Tomas lasted approximately 1 week (WASCO, pers. comm.). During the Christmas Eve Trough event there were significant damages to pipe networks which led to a water shortage on the entire island for up to 10 days (GOSL and World Bank, 2014). No information relating to dam outages from this event was identified.

Potential key project infrastructure components that may be vulnerable to climate are:

- **Existing John Compton Dam, Spillway and Pump House** – The dam structure, including the spillway and pump house, needs to withstand extreme weather events such as hurricanes and tropical storms that generate large amounts of rainfall and high winds. Floods associated with extreme events need to be safely conveyed over the spillway with sufficient freeboard (i.e., no dam overtopping). The pump house must also survive local landslides and debris associated with flow over the spillway.
- **Existing Roseau Reservoir** – Water volumes in the reservoir are affected by changes in annual and seasonal rainfall, evaporation rates, and extreme weather events. Changes in annual rainfall amounts will affect the amount of runoff that flows into the reservoir and the amount available for water supply. Increased evaporation rates would reduce reservoir water levels, which can impact the reliability of the water supply. Extreme weather events have the potential to increase the amount of sediment that would accumulate within the reservoir, ultimately impacting the amount of water available for water supply.
- **Proposed Sediment Disposal Area (SDA)** – The proposed sediment disposal area, including related water management structures (i.e., decant structures, outflow channels), need to be resilient for extreme rainfall events such as hurricanes and tropical storms. Annual operations within the SDA will also be affected by changes in monthly and annual rainfall (e.g., management of surface runoff water into the SDA).

- **Access Roads** – Access roads from the JCD to the SDA and JCD to Millet are important for operations. These roads can be impacted by landslides and washouts that occur during extreme weather events. Other existing infrastructure from Millet to the JCD, such as power and communication lines, is expected to have similar impacts from climate as access roads. This is because the infrastructure is installed along existing roads. This CVA only addresses impacts to local infrastructure and does not address the vulnerability of island-wide communication and power networks.

Climate is expected to have minimal impact on other project infrastructure components, such as the dredge barge, pipelines, and other related infrastructure.

## 10.2 Climate Variables of Interest

The primary climate variables of interest for John Compton Dam (JCD), based on the key vulnerable infrastructure are:

- Frequency of extreme weather events and large storms such as Hurricane Tomas and Tropical Storm Debby. Changes in the frequency of major storms will define the future requirements for reservoir sediment management, reservoir improvements, water management measures at the SDA, and impacts to local access.
- Annual and seasonal rainfall patterns, and in particular the frequency and magnitude of dry season drought events, that may impact water supply and annual operations of the SDA.

Other climate variables, such as sea surface temperature, sunshine hours, or wind speed are also of interest but play a lesser role in affecting key infrastructure. The CVA is focused on the primary climate variables because they directly impact water supply reliability.

## 10.3 Saint Lucia Climate

### 10.3.1 Previous Studies

Various studies have assessed the historical and projected climate change in Saint Lucia. The following reports have been reviewed as part of this study:

- UNDP Climate Change Country Profile: St. Lucia, 2010, prepared by McSweeney et al. (UNDP, 2010);
- Second National Communication on Climate Change for Saint Lucia, December 2011 (SNC, 2011);
- Climate Change Risk Atlas (CCCRA) - Saint Lucia, 2012, by Caribsave (Caribsave, 2012);
- Global Islands' Vulnerability Research, Adaptation, Policy and Development (GIVRAPD) Project Climate Modelling Report Summary, January 2013, by Caribsave (Caribsave, 2013); and
- Climate Change Adaption Planning in Latin American and Caribbean Cities – Saint Lucia, May 2012, by ICF GHK Consulting Ltd. (ICF, 2012).

An annotated description for each of these studies, as they pertain to potential impacts of climate change on Saint Lucia, is provided in Appendix L.

### 10.3.2 Historical and Current Climate

The climate trends for Saint Lucia, based on the available reports and analyses of climate records, indicate the following:

- **Temperature:** Recent temperature trends (since 1960) for Saint Lucia indicate that the mean annual temperature in St Lucia has increased by around 0.7˚C since 1960, at an average rate of 0.16˚C per decade (UNDP, 2010).

- **Rainfall:** Rainfall observations over Saint Lucia do not show statistically significant trends over the period 1960-2006. Long-term trends are difficult to identify due to the large inter-annual variability in rainfall in Saint Lucia (Caribsave, 2012; UNDP, 2010).

  Saint Lucia is already potentially experiencing changes in climate as demonstrated by several recent severe weather systems and frequent droughts (Caribsave, 2012; ICF, 2012). The historical record spans 124 years since 1890. Over that period, 9 of the 10 most severe droughts occurred within the past 35 years. This suggests that there is a potentially significant trend in the frequency and/or duration of droughts.

- **Extreme Weather Events:** North Atlantic hurricanes and tropical storms appear to have increased in intensity (storm size, wind speed, and rainfall amount) over the last 30 years, although there is still some debate whether this represents a long-term trend (Caribsave, 2013) or part of a natural cycle. Saint Lucia has been impacted by severe weather events including Hurricane Allen (1980), Tropical Storm Debby (1994), Hurricane Lenny (1999), Hurricane Dean (2007), Hurricane Tomas (2010), and the Christmas Trough (2013).

### 10.3.3 Climate Change Predictions

The expected future climate changes related to island hydrology are based on an interpretation of the available information. Available reports relied on global circulation models and regional climate models to predict changes up to the end of the century (UNDP, 2010; SNC, 2011; Caribsave 2012). This study interpreted the potential changes from a combination of recently observed climate data sources and climate model projections using an ensemble of 15 global climate models (GCMs) and the regional climate model (RCM), PRECIS (UNDP, 2010). The summary of climate change information for Saint Lucia is summarized below:

#### Rainfall

Future GCM rainfall projections indicate that changes in mean annual rainfall could range between -56% and +15% of the historical average by the 2090s, with ensemble median values of -10 to -22% (UNDP, 2010) as compared to the 30-year average from 1970-1999. This represents approximately an annual median rainfall reduction of up to 473 mm. The projected mean annual rainfall anomaly, according to various GCM scenarios, is shown on Figure 33.

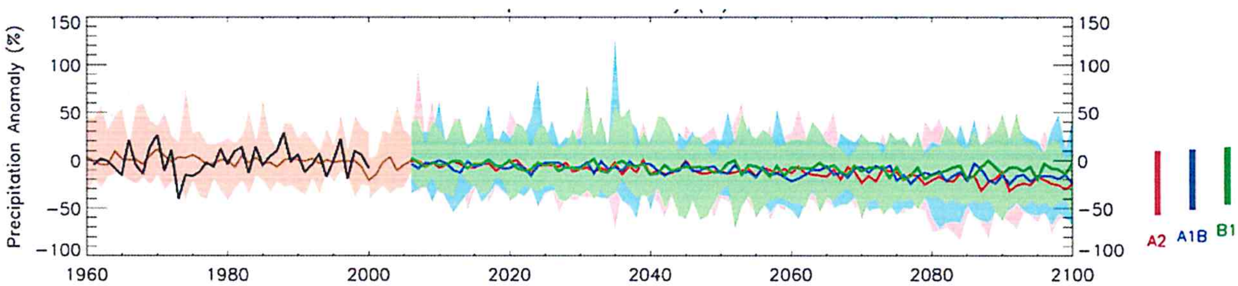
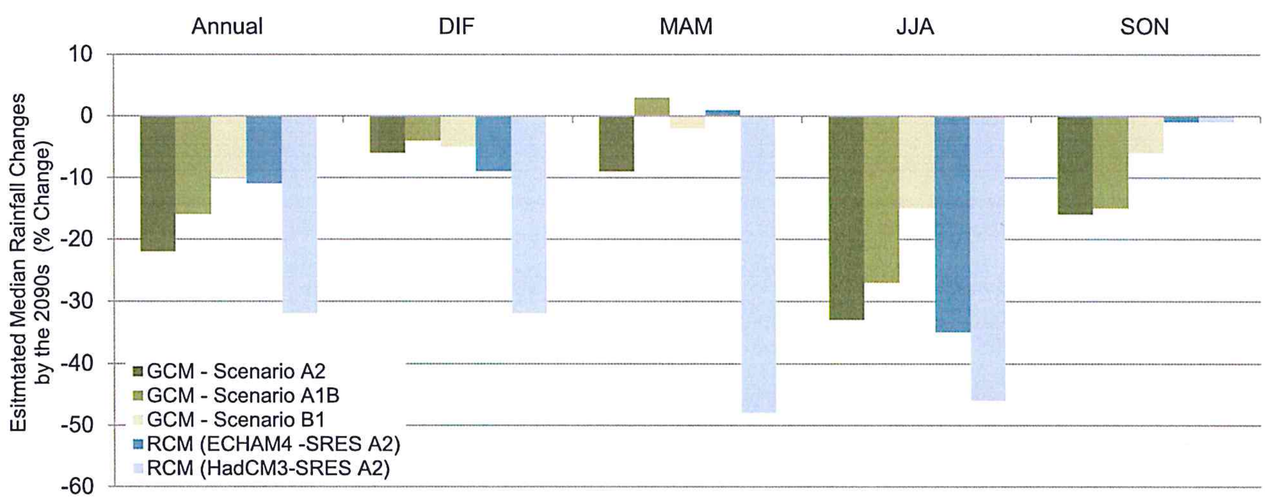



*Figure 33: Annual Rainfall Anomaly (%) for various GCM model scenarios (taken from UNDP, 2010)*

RCMs also predict less rainfall for the island on an annual basis, with median values of 11% and 32% less annual rainfall by the end of the century, depending on the regional model (SNC, 2011; Caribsave, 2012). This represents approximately an annual median rainfall reduction of up to 688 mm. Changes predicted by the RCM driven by HadCM3 are generally greater than ECHAM4-driven simulations as shown on Figure 34 (Caribsave, 2013). RCM projections of rainfall for Saint Lucia are strongly influenced by the selected GCM boundary conditions. When driven by HadCM3, the RCM predicts large decreases in rainfall in all seasons which is generally at odds with the other predictions.

Additional seasonal rainfall variability is also expected to occur by the end of the century (See Figure 34). Both GCM and RCM models generally indicate that the length of dry periods will increase (SNC, 2011). It is also expected that the dry period will occur earlier in the year. The wet season (June-July-August) is expected to be drier by about 15 to 33%, representing a monthly median rainfall reduction of up to 72 mm (UNDP, 2010). The dry season (December to May) is expected to be drier by up to 9%, equivalent to a monthly median rainfall reduction of up to 11 mm.




Note: GCM = Global Climate Model, RCM = Regional Climate model, ECHAM4-SRES A2 is a Global Climate Model developed by Max Planck Institute for Meteorology, HadCM3 = Hadley Centre Couple Model V3. Scenarios A1B, A2, and B1 refer various scenarios of future emissions.

*Figure 34: Annual and Seasonal Changes (%) in Rainfall from Various GCM and RCM Scenarios by 2090s (adapted from UNDP, 2010 and Caribsave, 2012)*

Finally, the models predict that the proportion of total rainfall that falls in heavy events will most likely decrease in most model predictions, changing by -26% to +6% by the 2090s. The maximum rainfall accumulation over one to five days tends to decrease, with 5-day maxima changing by -31 to +13 mm by the 2090s (UNDP, 2010).

### Tropical Storms and Hurricanes

GCMs and RCMs do not explicitly model hurricanes. Notwithstanding this important information gap, projections from the IPCC suggest that future hurricanes in the north tropical Atlantic will likely have greater peak wind speeds and heavier near-storm rainfall amounts. Stronger hurricanes (wind speed and rainfall amount) are expected to result from ongoing and predicted increases in tropical ocean temperatures and atmospheric water vapour content (SNC, 2011).

With regards to the frequency of tropical storms in future climate scenarios, predictions are strongly divergent. A wind speed study commissioned under the SPACC project in Saint Lucia (Vickery, 2008) suggests that climate change will result in three to four major hurricanes within the Atlantic Basin (Category 4 and 5) on an annual basis by 2025. This is more frequent than the current long-term average of 1.4 major hurricanes occurring within the Atlantic Basin. However, some RCM projections for the Caribbean indicate potential decreases in the frequency of tropical cyclone-like vortices under warming scenarios due to changes in wind shear (Caribsave, 2013). In addition several recent studies (e.g. Vecchi and Soden, 2007; Bengtssen et al., 2007; Knutson et al., 2008) have indicated that the frequency of storms may decrease due to decreases in vertical wind shear.

## 10.3.4 Selected Interpretation of Climate Change Projections

The following is the selected interpretation of predicted climate changes, for the purpose of water supply from John Compton Dam.

### Rainfall

- Mean annual rainfall is expected to decrease by up to 22% based on GCM models (decrease of 437 mm) and a decrease of up to 32% based on RCM models (decrease of 688 mm/year);
- Rainfall decreases are expected to occur during the wet season from July to November;
- Wet season (June-July-August) is expected to be drier by about 15 to 33% according to the GCM (mean decrease of 72 mm/month); and
- Dry season (December to May) is expected to be drier by up to 9% according to the GCM (mean decrease of 11 mm/month).

### Tropical Storm and Hurricanes

- An increase in hurricane intensity has been noted over the past 30 years;
- Climate studies and model predictions indicate that the intensity of hurricanes and tropical storms may increase (i.e., peak wind speed and rainfall); and
- Changes in frequency of tropical storms in future climate scenarios are inconclusive:
  - Frequency of major hurricanes in the Atlantic Basin may increase from 1.4 per year to about 3.5 per year (Vickery, 2008), and

- Frequency of tropical storms may decrease due to changes in wind shear estimated in the climate models (Caribsave, 2013).

## 10.4 Impacts of Climate Change on Key Infrastructure

### 10.4.1 Dam Structure and Spillway

Raising the existing wave wall will mitigate potential increases in the intensity and frequency of large weather events. From the preliminary freeboard analysis on various extreme flooding events, the wave wall would need to be increased by up to 1.7 m to 108.2 m. Previous recommendations by Halcrow (2011) suggest raising the wave wall by 1.2 m so that there is sufficient freeboard during the 10,000-year event. Impacts of potential climate change were assessed by estimating the sensitivity of the freeboard from changes in the PMP (Table 9). An estimation of the PMP and the relationship between the PMF and the 10,000-year peak flow is documented in Section 2.10. If the 10,000-year peak flow was to increase by roughly 20%, the freeboard would need to be increased to 2.5 m. Any increases to the height of the wave wall would likely require increases to the crest of the dam to provide proper support for an enlarged wave wall.

**Table 9: Sensitivity of Freeboard to PMP Changes**

| Freeboard Assessment | Estimated Change in PMP | | | | | | |
|---|---|---|---|---|---|---|---|
| | -10% | -5% | 0% | +5% | +10% | +15% | +20% |
| 10,000-year peak inflow [$m^3$/s] | 660 | 700 | 730 | 770 | 810 | 850 | 880 |
| Peak water level [masl] | 107.1 | 107.3 | 107.5 | 107.7 | 107.9 | 108.1 | 108.3 |
| Wave wall raise height [m] | 1.3 | 1.5 | 1.7 | 1.9 | 2.1 | 2.3 | 2.5 |

### 10.4.2 Roseau Reservoir Water Supply

#### Water Supply Reliability

Changing rainfall patterns may result in changes to water availability for drinking water supply. Decreased rainfall will result in decreased inflow to the Roseau Reservoir, and potentially in longer intervals between spilling. The potential climate change scenarios were evaluated based on a water balance model calibrated for local conditions. The model simulates watershed runoff and dam operations for the historical period from 1985 to 2014, roughly coinciding with the period of most severe drought events. With the mean annual rainfall decreasing on average by up to -22% by 2090, the water rationing is expected to be required more frequently; reducing the water supply reliability to about 83% and increasing the potential for a major water supply failure to once in 10 years on average by 2090. A summary of the assessment results is provided in Table 10.

**Table 10: Sensitivity of Water Supply Reliability to Climate Change**

| Water Supply Assessment | Mean Change in Annual Rainfall | | | | | | |
|---|---|---|---|---|---|---|---|
| | +20% | +10% | 0 | -10% | -20% | -30% | -40% |
| Reliability (rationing) | 97% | 97% | 90% | 83% | 83% | 67% | 40% |
| Reliability (failure) | 97% | 97% | 97% | 90% | 83% | 67% | 50% |

The *water supply assessment* partially accounts for future climate change by focusing the assessment on the historical period from 1985 to 2014. This period includes the drought of record (2001) plus several large storm events (i.e., Hurricane Debby, Hurricane Tomas and the Christmas Storm in 2013). The drought of record is a 100-year return period event, but is interpreted as the equivalent of a 30-year event when considering the selected period from 1985 to 2014. The current water supply assessment therefore over-estimates the frequency of the 2001 drought compared to the entire historical record. This is an assumption that is intended as a conservative planning basis to account for some future climate change. Specific climate predictions are not available for hurricane intensity.

### Reservoir Sedimentation

Future reservoir sedimentation occurs largely during extreme weather events (e.g., Hurricane Tomas, Christmas Trough, Tropical Storm Debby). The intensity (hurricane category, rainfall amounts, and wind speeds) and frequency of extreme weather events may increase due to climate changes. Changes to extreme weather patterns may increase the amount of sediment deposited in the reservoir.

The majority of reservoir sediment is due to landslides and associated debris flows. There are at least 2 locations identified along the reservoir with steep slopes along a drainage path that has not yet formed a landslide. In addition to new future landslides, the existing landslide areas are expected to deliver additional sediment to the reservoir where the landslides have formed alluvial fans that may be re-mobilized during a storm.

The de-silting plan assumes that the most recent period of 30 years will represent the future conditions. The selection of this period is relatively conservative in that it represents the most severe historical climate cycle on record. By using this selected period, hurricanes such as Tomas are conservatively assumed to occur every 20 years and tropical storms (such as Debby) will occur every 10 years on average, despite other estimates that have reported Tomas to be a much more extreme 180-year return period event.

The reservoir will be de-silted at a rate that is greater than the long-term average sedimentation, whereby the long-term average includes events such as Tomas, Debby, and the Christmas storm. The calculated long-term average sediment yield conservatively assumes that every large storm (tropical storm and hurricane) will deliver large volumes of sediment into the reservoir, and the selected de-silting rate is about 50% more than the long-term average. The amount of sediment delivered to the reservoir varies from year to year, so the de-silting plan may not always add storage capacity during high sediment years. Additional dredging is most likely needed over the next 10 years, depending on the timing of future storms and associated sedimentation events.

### Resiliency after a Large Storm

The proposed small-scale continuous dredging program provides WASCO with the required resiliency by removing sediment and daylighting the lower intake port within 21 days if needed. After a large storm delivers sediment to the reservoir, the lower intake port may become covered by silt again. This may leave WASCO with as little as 40 days water supply if a drought were to occur immediately following the large event (i.e. similar to 2014). The dredge location would need to be moved to the face of the dam, and the intake sediment could be removed on an emergency basis.

In addition to emergency daylighting of the lower intake port, a large storm may deposit a large volume of sediment within the reservoir. Some of this sediment is expected to be trapped on the upstream beach, but the overall reservoir storage capacity will likely be reduced. This may temporarily reduce the water supply reliability until more sediment can be removed. The expected water supply reliability for various accumulations of sediment in the reservoir is shown in Table 11, which indicates that another "Debby" or "Christmas storm" sedimentation event (i.e. up to 200,000 $m^3$ of additional sediment in the reservoir) in the near-term will not require more frequent water rationing as long as the lower intake port remains available for water abstraction.

Overall, the selected de-silting plan has allowed for 10 years preparing for the next Tomas-like sedimentation event. If another "Tomas" sedimentation event occurred within the next 10 years, additional utilization of the dredge may be needed to quickly recover and avoid frequent water rationing. The de-silting plan is flexible in that WASCO will have the option to temporarily increase the amount of dredging by adding extra work shifts as needed to increase dredge utilization.

**Table 11: Sensitivity of Water Supply Reliability to Additional Reservoir Sedimentation**

| Water Supply Assessment | Increase in Reservoir Sediment Compared to 2014 [$m^3$] | | | | | |
|---|---|---|---|---|---|---|
| | 0 | 50,000 | 100,000 | 200,000 | 400,000 | 500,000 |
| Reliability (rationing) | 90% | 90% | 90% | 90% | 83% | 83% |
| Reliability (failure) | 97% | 97% | 93% | 93% | 90% | 87% |

Note: This table assumes that the lower intake is available for water abstraction.

### 10.4.3 JCD Pump House

The Pump House at JCD was impacted during Hurricane Tomas by two hazards:

- Large woody debris (LWD) damaged the roof of the pump shelter. The LWD was likely ejected from the stilling basin after discharging over the spillway.
- A local landslide near the pump house deposited sediment in the vicinity of the pumps.

The pump house is expected to be protected in the future by constructing an L-shaped wave wall along 3 sides of the pump house to resist water impact loads.

### 10.4.4 Sediment Disposal Area

Extreme weather may also impact the sediment disposal area (SDA). Water conveyance is necessary to prevent dyke overtopping and potential breaching of the dyke. The dyke freeboard is sized to store runoff from large events, plus additional conveyance capacity via an emergency spillway structure. This combination of containment and conveyance is expected to be sufficient for an equivalent 10,000-year event, based on the following assumptions:

- Dyke freeboard provides storage capacity for the 24-hour duration 100-year return period event.
- Spillway capacity provides additional conveyance equivalent to more than the 100-year return period peak flow.
- The 100-year 24-hour rainfall intensity was estimated at 15 mm/hr, and the 200-year intensity is 17 mm/hr. The rainfall intensity for various floods was estimated for the JCD area by a hydrology study conducted by Klohn Krippen (1995). The hydrology study took available daily and hourly data from nearby climate stations around the island to develop intensity-duration-frequency curves.
- The maximum runoff volume was based on a total drainage area of 22.5 ha upslope of the full build-out SDA, plus rainfall directly to the SDA.

The SDA containment and conveyance requirements could be affected by climate changes, although climate predictions do not indicate a potential increase of rainfall intensity. The sensitivity of rainfall intensity to the projected runoff volume is shown in Table 12.

**Table 12: Sensitivity of SDA Stormwater Volume to Climate Change**

| | Change in 24-hour Rainfall Intensity [%] | | | | | | |
|---|---|---|---|---|---|---|---|
| | +0% | +5% | +10% | +15% | +20% | +25% | +30% |
| Rainfall Intensity [mm/hr] | 15 | 15.8 | 16.5 | 17.3 | 18.0 | 18.8 | 19.5 |
| Runoff Rate [$m^3$/s] | 0.77 | 0.81 | 0.85 | 0.88 | 0.92 | 0.96 | 1.00 |
| Runoff Volume [$m^3$] | 66,400 | 69,700 | 73,000 | 76,300 | 79,700 | 83,000 | 86,300 |

### 10.4.5 Access Roads

Access roads from Millet to the JCD, and from the JCD to the SDA, may also be impacted during extreme weather events. Extreme weather events can cause landslides and washouts along these roads, potentially making them impassable. WASCO manages temporary road loss hazards by maintaining the existing roads according to best practices, and by arranging for emergency road maintenance after a washout. The current possibility for temporary road loss is about 5% each year, assuming that the road may be washed out during events similar to the Tomas hurricane.

In the future, a second road access may be constructed through Dame de Traversay as part of a sediment re-use plan. This would provide a second opportunity for access or egress, and further reduce the risk of loss of access by about 50%. A detailed evaluation of a new access road has not been included in this report and will need to be further developed if a business case is developed.

## 10.5 Conclusions

The JCD Rehabilitation Plan is expected to provide a robust and resilient response to climate change. Specific threats to infrastructure are addressed by the plan, and the plan provides a flexible strategy for adjusting to changing climate conditions. Climate variability and long-term changes have the potential to deposit additional sediment in the reservoir, despite the use of conservative estimates for sediment yield. This change would be addressed by adjusting the pace of dredging. The change is possible because the selected plan is based on long-term future dredging each year using a relatively small dredge. The pace of dredging could be adjusted by simply increasing the dredging hours per day or the length of the dredging season. By contrast, a large dredge could remove sediment more quickly, but would then be decommissioned. After decommissioning, the large dredge would require significant effort to re-mobilize and is therefore poorly-suited to respond to changing climate conditions or short-term climate variability.

# 11.0 RECOMMENDED NEXT STEPS

The recommended next steps are to:

- Implement the recommended improvements at emergency water sources (WASCO);
- Communicate the de-silting and rehabilitation progress to stakeholders (WASCO);
- Pre-qualification of dredging contractors (WASCO);
- Revise the De-Silting and Rehabilitation Plan Report, based on comments by WASCO, GOSL, CDB, and EIB (Golder);
- Submit the plan to funding agencies for review (WASCO);
- Geotechnical investigation at the old laydown area to define surficial ground conditions (see Appendix P);
- Purchase land required for the dredging plan (WASCO);
- Contract the initial dredging work (WASCO);
- Contract the long-term dredging operations (WASCO);
- Contract the engineering support through construction (WASCO);
- Implement the Source Water Protection Plan in collaboration with Forestry (WASCO); and
- Develop a sediment re-use program (WASCO).

# Report Signature Page

This report was prepared by Golder Associates Ltd. (Canada), in association with Morrison Hershfield (Canada), Strata Engineering (Saint Lucia), and Amarna Consult (Saint Lucia). Golder Associates Ltd. assumes overall responsibility for the work.

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