Wastewater Treatment and Reuse and Cost Benefit Analysis

**FEASIBILITY STUDY FOR DEVELOPING
A CENTRALIZED SEWAGE TREATMENT AND COLLECTION SYSTEM
IN THE CITY OF SPANISH TOWN, ST. CATHERINE, JAMAICA**

Mr. Adhem Mukattash, Project Manager, Water Infrastructure, Cole Engineering Group Ltd., 70 Valleywood Dr., Markham, Ontario, L3R 4T5, Canada

Dr. Muin Husain, Cole Engineering Group Ltd., Vice President, Environment and Energy, 70 Valleywood Dr., Markham, Ontario, L3R 4T5, Canada

Mr. Derian Jackson, Project Manager, National Water Commission, 5th floor, Sagicor Building, 28-48 Barbados Avenue, Kingston 5, Jamaica, West Indies

Mr. Andrew Moreton, Business Unit Leader, Municipal Infrastructure, Cole Engineering Group Ltd., Environment and Energy, 70 Valleywood Dr., Markham, Ontario, L3R 4T5, Canada

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Abstract

In the Caribbean, non-revenue water (NRW) is an issue that has been significantly impacting the efficiency of service delivery in water and wastewater utilities. In Jamaica, this issue is also quite prevalent. As a result, the country's water and wastewater service provider, National Water Commission (NWC), is taking steps to improve existing operating efficiencies of water production and distribution and sewerage systems. To aid with this endeavour, Cole Engineering Group Ltd. (CEG), funded by the Inter-American

Development Bank (IDB), was retained to complete a feasibility study on the wastewater aspects in the city of Spanish Town, St. Catherine, Jamaica.

Currently in Spanish Town, there are decentralized treatment plants servicing different residential developments. To maximize the efficiency of wastewater management, the feasibility of a centralized treatment and collection system was assessed. This study involved looking into engineering, environmental and social aspects of a centralized system, along with preliminary financial and economic assessments. The analysis was completed using existing information provided by NWC and other local organizations, as well as through field surveys and investigations. The current condition of the existing assets and operating practices were benchmarked. Alternative wastewater servicing options were developed, and a series of evaluation criteria covering the environmental, social, regulatory, financial and conceptual design aspects were used to weigh the risks and benefits of each option to ultimately recommend the preferred solution. The study will serve as a guide for NWC during the detailed design phase in order to maximize the efficiency of wastewater management in Spanish Town. Key recommendations included: improvement of sewage collection, conveyance, and treatment in targeted areas; reduction of pollution to receiving surface water; retirement of the decentralized packaged sewerage facilities; and incremental reduction in operations and maintenance costs associated with the service provision.

Background

National Water Commission (NWC) is the statutory organisation charged with the responsibility of providing water supply and sewerage services in Jamaica. One of the

major goals of NWC is to increase access to central sewerage services to at least 35% of the population (from a current 14%) within the medium-term. The long-term objective is for the 22 largest urban centres, which accounts for more than 50% of the population, to have central sewerage systems by 2030.

Spanish Town, Jamaica's first capital, has no central sewerage system in the majority of the town. Currently, there are 8 small discrete treatment plants servicing small developments in Spanish Town and its environs. NWC intends to establish a central sewerage collection and treatment system for the Spanish Town service area, and retire and convert the small packaged treatment plants into wastewater pumping stations.

Cole Engineering Group Limited (CEG), a Canadian engineering consulting firm, was contracted through an international competitive bidding process funded by the Inter-American Development Bank (IDB), to prepare a master plan for a central collection and treatment sewerage system for Spanish Town, Jamaica. The services provided by CEG over the six-month contractual period encompass data collection, investigation, options analysis, master planning with recommendations, and financial and economic analysis.

Problem Statement

Spanish Town, St. Catherine, Jamaica, is currently partially served by discrete sewage collection and treatment systems. The existing packaged treatment plants, serving 19% of the project area are in varying states of disrepair and most do not meet the required environmental standards of the country's environmental watchdog, the National Environmental Planning Agency (NEPA), for effluent discharge. The study

objective was to develop a plan for servicing the Spanish Town area with sewerage collection and treatment systems, while meeting NEPA effluent criteria.

Purpose

The purpose of this paper is to present a summary report of the master plan and preliminary design prepared by CEG and outline the process involved.

Data Collection and Analysis

To facilitate the study within the timeline allotted, an extensive data collection exercise was undertaken. Data and reports that would inform the study and provide the basis for development of the preferred solution were collected from numerous agencies. Furthermore, to ensure timely transfer of data, a local individual who is familiar with the processes and copyrights laws was selected by CEG to act as the liaison between NWC, other agencies and CEG.

The data collated was used to determine the design hydraulic and organic loads for the new central wastewater treatment facility with a design horizon of 50 years. The design hydraulic load was determined using data from NWC's Customer Billing Database and Population Census Data. Information from NWC's Customer Billing Database and Census 2011 population records were used to undertake a water audit assessment to determine the per capita consumption. Sewage flows were calculated by multiplying the predicted 2071 populations and the per-capita average flows of 141 L/c/d. Non-residential sewage flows were estimated following an established criteria developed during the study.

At the same time, Population Census Data was used to project the population growth rate over the design horizon, by means of the geometric growth method. Nonetheless, there were limitations to the data received, such as:

- production flow data provided was for the entire parish of St. Catherine due to the integrated nature of the water supply systems in the parish; and
- there were inconsistencies between the census data and NWC's billing data accounts.

Both of the above issues were resolved by undertaking the water audit for the parish of St. Catherine under the following assumptions:

1. The current calculated residential, commercial and industrial per capita consumption will remain unchanged over the design horizon;
2. The per capita consumption is constant for the parish of St. Catherine;
3. 90% of the water used will return to the sewers (return factor);
4. Infiltration/inflow rate for existing sewers is the same in the parish of Kingston and St. Catherine;
5. Only 90% of the population in the sewered areas are connected; and
6. The quality of the influent in the existing sewered areas will not change.

Concurrently, a detailed facility condition assessment as well as a preliminary aerial survey (using Google professional) were carried out on the 8 discrete treatment plants. Information gathered from the condition assessment was used to analyse the options available for the transfer of sewage from each discrete treatment plant to the proposed central treatment system.

From the records of the influent concentrations of the sewage treated by the existing eight packaged treatment plant in Spanish Town, the raw sewage can be generally categorised as medium strength wastewater which correlates with the raw sewage categorization specified by NEPA. However, based on the recommendations from both the NWC and Cole Engineering project teams, the influent TSS, BOD_5 and TP concentrations were increased to the range of high strength raw wastewater. In addition, because the per capita flow rate used for estimating the sewage flow is low, Metcalfe and Eddy (2003) recommended the use of high strength wastewater concentration. This is illustrated in **Table 1** below.

Table 1: NEPA Influent and Effluent Specifications and CWWTP Design Values

Parameter	NEPA Design specifications	CWWTP Design Specifications	NEPA Effluent Limit		Unit
			Direct Discharge	Irrigation	
TSS	220	400	30	15	mg/L
BOD_5	250	350	20	15	mg/L
COD	500	800	100	<100	mg/L
TN	40	40	10	NA	mg/L
TP	8	16	4	NA	mg/L
pH	6 -9	6-9	6 -9	NA	
Temperature	28	28			^{O}C

Alternatives Analysis & Selection of Preferred Solution

A two-phased approach was used to select the preferred solution for development. Initially, all the possible alternatives available to address the aforementioned problem statement were identified and screened against qualitatively-assessed criteria, to remove the alternatives which did not meet the criteria. To ensure thorough assessment of alternatives, two separate assessments involving assessing alternatives against criteria

were done for the *"central sewerage collection network"* and the *"central sewage treatment facility*".

Four criteria, namely **technology, environmental impact, social/cultural/legal impact, and financial impact**, were used for the initial screening of alternatives. Considerations such as location of treatment facility and incorporation of existing sewerage systems were given to the *"central sewerage collection network"* assessment. Matters such as treatment technologies and ease of operations and maintenance were granted to the selection of preferred alternative for the *"central sewage treatment facility".* Each alternative was evaluated on a pass or fail basis, and each alternative must "pass" each of the criteria listed above to be considered for the short-list of alternatives.

The following alternatives resulted from the initial screening process:

- Central Sewage Collection Network
    - Alternative 1 - Develop a new centralized sewerage collection network that culminates at the south-west end of the Spanish Town boundary and retire and convert the existing plants into lift stations.
    - Alternative 2 - Develop a central sewerage network that flows to an existing treatment plant (to be upgraded) located on the north-west boundary of Spanish Town; and retire and convert the existing plants into lift stations.
    - Alternative 3 - Develop a new treatment plant and at the same time upgrade one of the existing treatment plants.
- Central Sewage Treatment Facility

The following treatment technologies were considered most suitable when assessed against criteria such as treatment performance, life cycle cost, operational complexity, etc.:

- Alternative A - Extended aeration activated sludge;
- Alternative B - Sequencing batch reactor; and
- Alternative C - Facultative Lagoons/wastewater stabilization ponds.

To arrive at the favoured alternative, a team consisting of personnel from NWC and CEG project teams conducted a detailed assessment on the alternatives listed above for both the central sewerage collection network and central sewage treatment facility. The assessment included a weighted average analysis using the four criteria listed above with assigned weightings and rankings for each criterion and their respective sub-criteria. Weightings ranging between ten (10) and twenty (20) were assigned to each criterion and sub-criteria and rankings (as detailed below), ranging from zero (0) to four (4) were also used to arrive at a final weighted average (total score). Quantitative analysis was carried out to evaluate the options on the basis of their technicality and financial impact, whereas a qualitative approach was used to judge the options on the basis of environmental and social impacts.

Rankings

Zero (0)	-	Does not fulfil criteria/sub-criteria
One (1)	-	Partially satisfies criteria/sub-criteria
Two (2)	-	Fairly satisfies criteria/sub-criteria
Three (3)	-	Substantially satisfies criteria/sub-criteria
Four (4)	-	Completely satisfies criteria/sub-criteria

Results of the options analysis are presented in **Table 2** and **Table 3** below.

Table 2 - Central Sewage Collection Network

Criteria	Criteria Weighting	Alternative 1	Alternative 2	Alternative 3
Technical	17			
Environmental	15			
Social/Cultural/Legal	13			
Financial	17			
Weighted Average		**1003**	**990**	**758**
Ranking		**1**	**2**	**3**

Table 3 - Central Sewage Treatment Facility

Criteria	Criteria Weighting	Alternative A	Alternative B	Alternative C
Technical	18			
Environmental	15			
Social/Cultural/Legal	12			
Financial	17			
Total Score		**1154**	**953**	**1072**
Ranking		**1**	**3**	**2**

Solution Development

Preliminary designs were thereafter prepared for the preferred solution for the sewage collection network and sewage treatment facility (Alternative 1 & Alternative A). The preliminary design for the central collection network took into account the hydraulic

design for the sizing of the trunk sewers (using Manning's equation) and retiring of the existing plants as well as preliminary plan and profiles for the trunk sewer network.

The design hydraulic and organic loadings determined from the data analysis were used to size the proposed treatment facility. The preliminary engineering package for the proposed central wastewater treatment plant includes:

1. Process description;
2. Process flow diagram;
3. Mass Balance;
4. General layout of the treatment plant;
5. Estimated consumption of utilities and chemicals;
6. Operation, Maintenance and troubleshooting;
7. Capital cost estimate;
8. Operation and maintenance cost estimate; and
9. Estimated construction schedule.

Recommended Solution

The recommended approach for the solution of the sewage collection and treatment problem in Spanish Town includes: Centralised WWTP, Two-Trunk Sewer Network (East and West Truck) and Lateral Collection System.

A) Central Sewer Network

Using the available contour maps, the sanitary network was built using a series of nodes and sewer pipelines, taking advantage of the natural slope of the land. Once the

network had been established, the sanitary drainage areas were then delineated for each node in the network.

As shown in **Figure 1** below, the nodes are numbered 1A to 25A including node WWTP which represents the collection chamber within the central wastewater treatment plant. Each corresponding sub-catchment is similarly numbered to indicate the corresponding drainage to node.

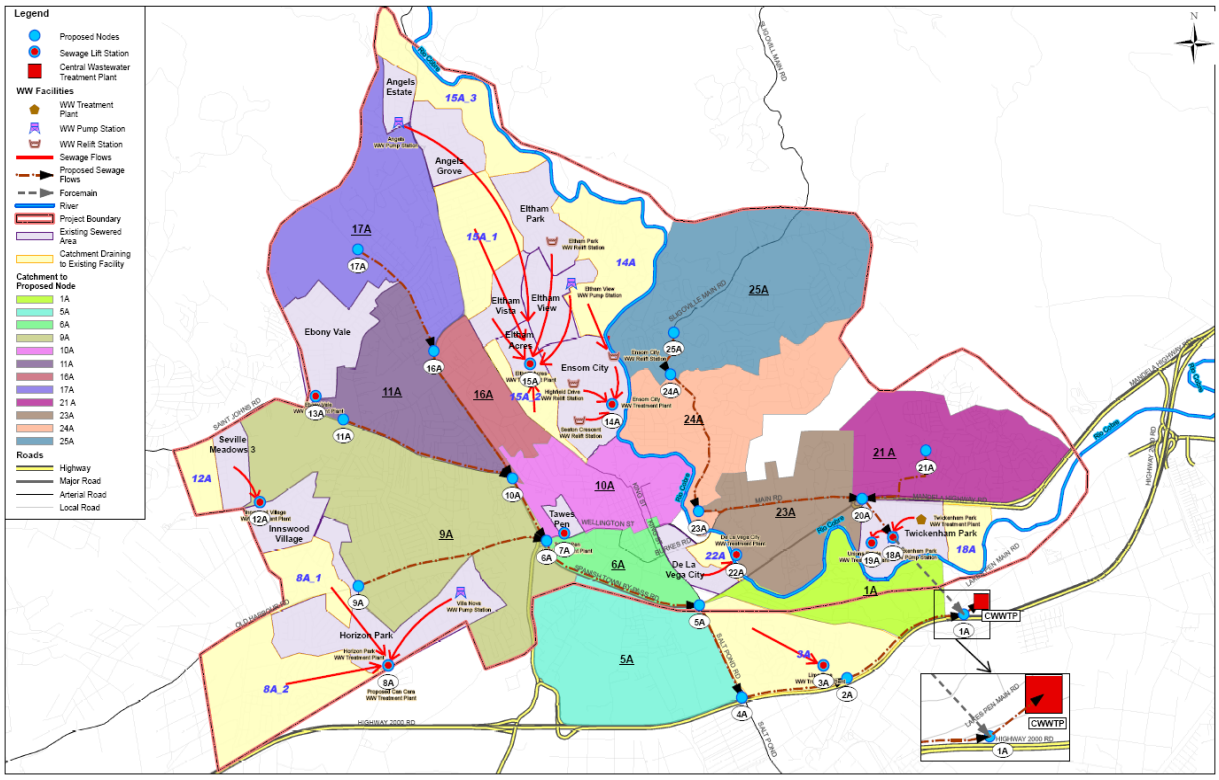

Figure 1: Catchments of Spanish Town

To allocate sewage flows to the trunk sewers, the catchments were overlaid with the 2011 Census Enumeration Districts and the population within each catchment was calculated. (Populations from partial Enumeration Districts were allocated by proportion of area within the catchment.) The predicted 2071 population of each catchment was also

calculated, based on the growth rates for each parish established based on population growth prediction prepared for project purposes.

The inflow and infiltration contribution to the Darling Street Pumping Station in downtown Kingston was estimated to be 1.3 m^3/ha/day and was correspondingly applied across the project area for the water audit, however, the infiltration rate for a newly constructed sewer system using watertight joints of PVC and GRP is expected to yield lower rates considering no inflow contribution. Infiltration rates used for the design of new sewer pipes is 10 L/mm-dia/km/day.

Based on the topography of the area, existing local WWTP and the hydraulic design considerations, the sewer network design approach was based on the preferential of gravity flow over pumping and forcemains in order to optimize the operational and maintenance cost.

Several construction methods were considered during the study including the open trench and trenchless methods and recommendations made based on the topography, groundwater table, land-use, and other considerations.

B) <u>Central Sewage Treatment Plant</u>

The schematic flow diagram of the selected wastewater treatment facility is shown in Error! Reference source not found. The liquid process train includes bar screen, pump station, aerated grit removal channel, primary sedimentation tanks, bioreactors, secondary sedimentation tanks, parshall flume, chlorination contact basin and effluent outfall structure. The effluent will be discharged into the Rio Cobre River. The sludge or solid process train includes sludge blend tank, anaerobic digester and sludge dying beds.

The biosolids are land applied while the scum, screenings, grit and unused biosolids are deposited in a land fill.

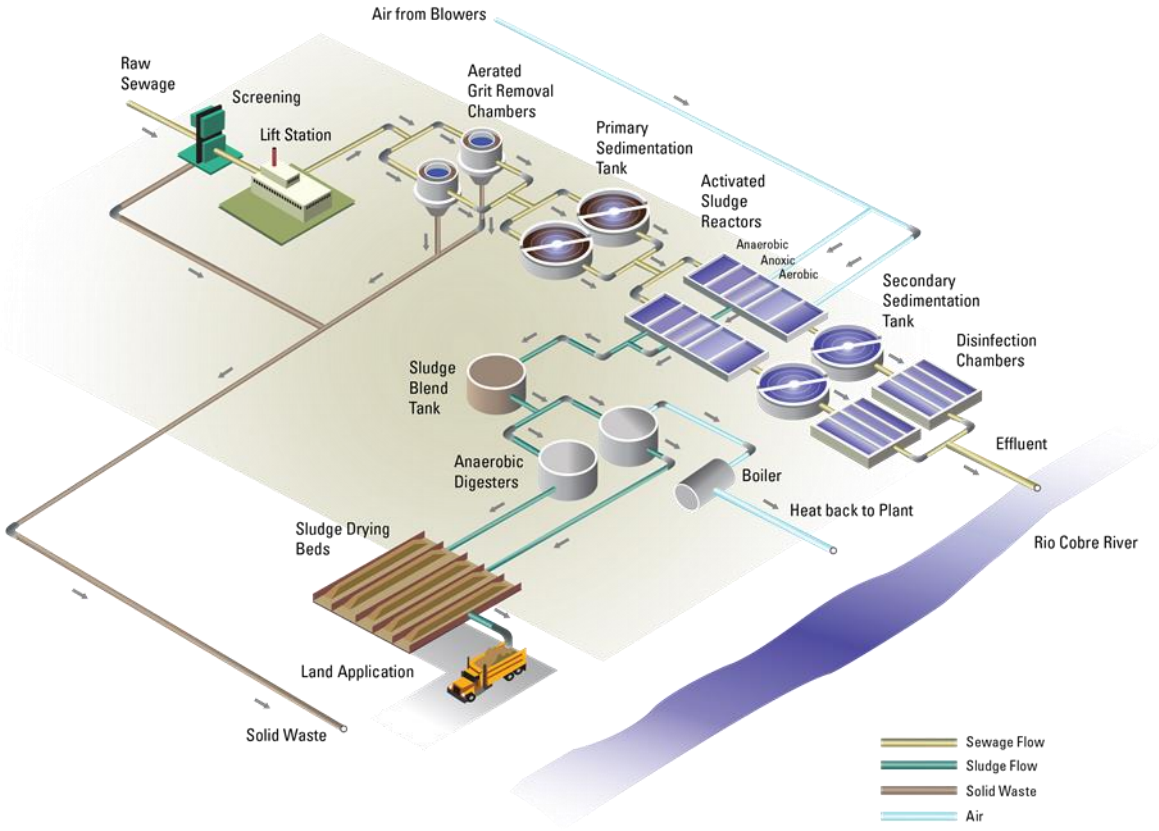

Figure 2: Flow Schematic of Selected Wastewater Treatment Plant

C) Implementation and Construction Plan

The Implementation of the recommended solutions is separated into four timely-mannered phases throughout the project life cycle 2021-2071. The phases will take place to gradually cover the entire Spanish Town population and area by the year 2071 including any expected growth. For the purpose of the sewerage and treatment system, the Spanish Town development plan was divided into four phases. The phasing allows for flexibility and adaptability of the sewage collection and treatment in response to the

development within the project area while maintaining minimum sewage flows and organic loadings required to support the biological processes responsible for the treatment of the wastewater throughout all phases of development. A phased approach will enable reduction in initial capital cost and operation and maintenance costs. Further details on the phasing are provided in the following sections. **Figures 3**, **4**, and **5** depict Phase 1, 2 and 3 of the project, while Phase 4 will only contain expansion in WWTP to adapt population growth over the time. For Phase 1, the project work is planned to be executed according to the following work segments:

- **Work Segment 1** - Upgrade some of the packaged WWTPs to improve their performance so as to meet the NEPA effluent requirements while awaiting the approval, construction and commissioning of the central WWTP.
- **Work Segment 2** - Complete the design for the sewerage network. This will include conducting all required surveys and investigations to collect the data necessary to develop the design.
- **Work Segment 3** – Complete the detailed design of Phase 1 of the central wastewater treatment plant.
- **Work Segment 4** – Construction of Phase 1 of the new central wastewater treatment plant that will meet the NEPA's effluent quality criteria. The central WWTP would be designed in four phases for a 2071 design year with ultimate projected population of 486,324 and a daily average volumetric flow rate of 83,000 m^3/d.

- **Work Segment 5** – Construction of Phase 1 of the sewerage network. This work will include decommissioning and conversion of selected packaged WWTPs into pumping stations.

Table 5: Development Plan and Sewage Flow Summary by Phase

	Phase 1	Phase 2 Expansion	Phase 3 Expansion	Phase 4 Expansion
Construction Year	2019	2031	2046	2060
WWTP Commissioning Year	2021	2032	2047	2061
Design Year	2031	2046	2061	2071
Design Year Population	208,711	77,913	106,999	92,701
Cumulative Population served	208,711	286,624	393,623	486,324
Calculated WWTP Flows (m^3/d)	**35,063**	**13,089**	**17,976**	**15,574**
Actual WWTP Design Flow (m^3/d)	**35,000**	**14,000**	**18,000**	**16,000**

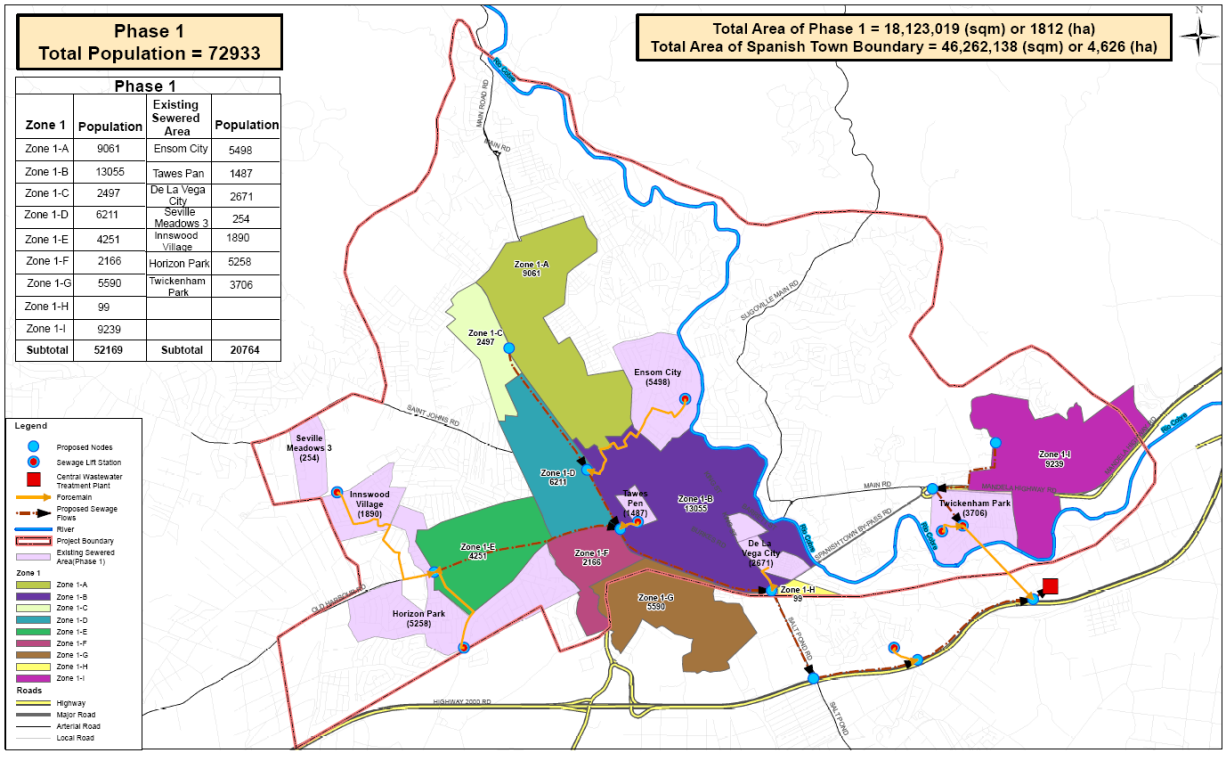

Figure 3: Map of Phase 1 Construction of the Collection System

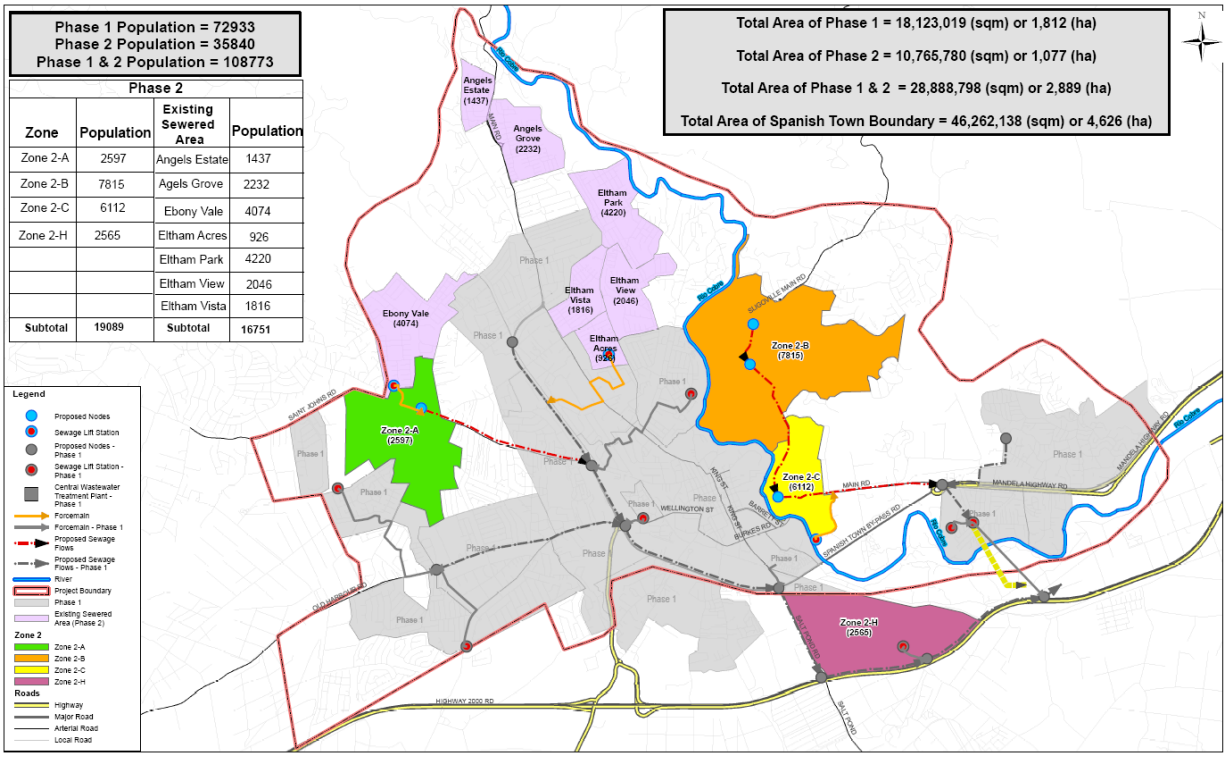

Figure 4 Map of Phase 2 Construction of the Collection System

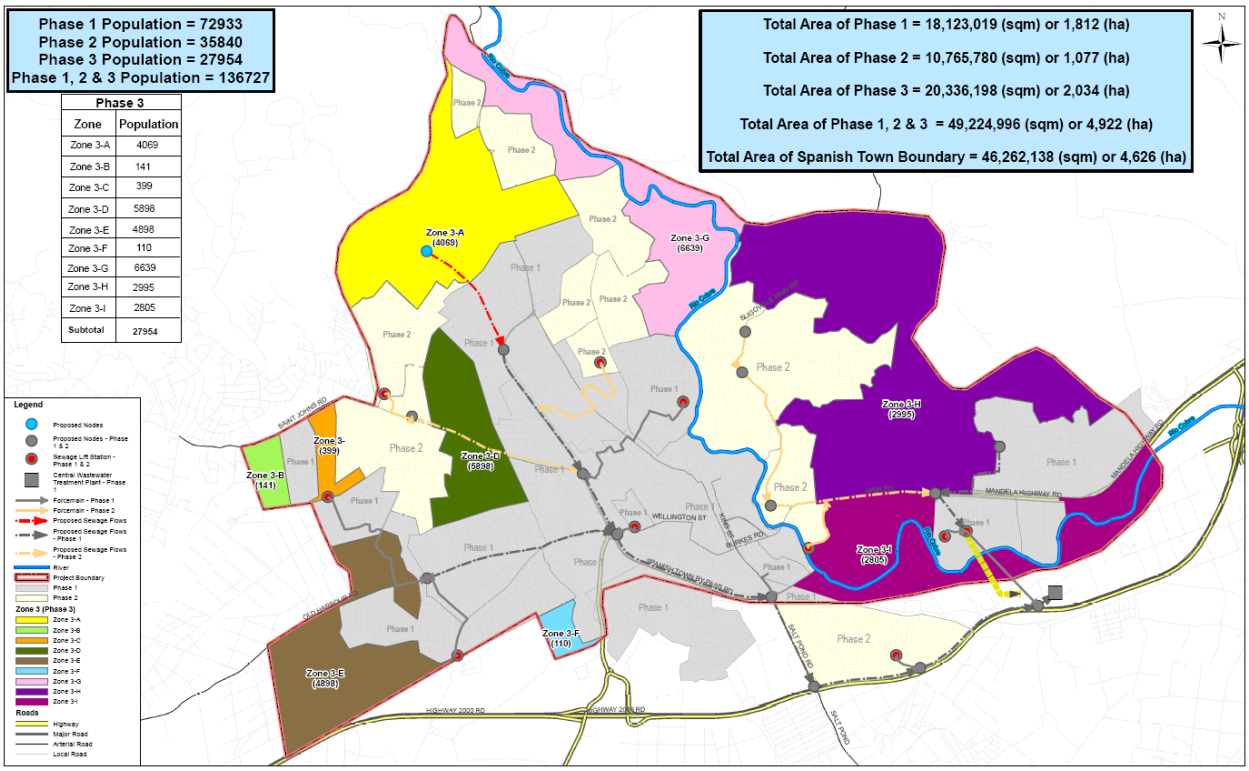

Figure 5 Map of Phase 3 Construction of the Collection System

Construction Cost Estimates and Financial Analysis

The preliminary capital cost for construction of the new facility was estimatedError! Reference source not found.. This cost estimate should be considered as an ASTM Class 4 estimate with an implied accuracy range of -20% to +30%. The total cost of construction for the entire sewerage network is estimated at approximately USD 425M while the total cost of constructing a CWWTP to service the overall population within the project area in Spanish Town is estimated at USD 101.4M.

Conclusion

Cole Engineering Group Limited has completed the Master Plan inclusive of preliminary design of a central sewage collection and treatment system that will service the population within the project area in Spanish Town, Jamaica until the year 2071 on behalf of National Water Commission. The plan is for the project to be implemented in four phases over the design horizon up to 2071.

Biographies

Derian Jackson, PE, PMP, MBA

Derian Jackson is a professional engineer with a Bachelor of Engineering degree in Chemical Engineering, from the University of Technology, Jamaica. He is also the holder of Master's degree in Business Administration from the University of the West Indies. Mr. Jackson is a seasoned Project Manager with over 8 years of experience administering water and wastewater infrastructures, including overseeing multimillion dollar sewer and potable water design and construction projects involving national and international partners. His experience also includes working with multilateral funding agencies such as the Inter-American Development Bank and the European Union.

Contact Information: National Water Commission, 28-48, Barbados Avenue, Kingston 5, Jamaica; derian.jackson@nwc.com.jm

Adhem Mukattash has a B.Sc. in Civil Engineering, majoring in Water Resources and Environmental Engineering, from the Jordan University of Science and Technology in 2005, and a M.Sc. in Environmental Engineering from the University of Central Florida in 2007. He is also PMP-certified. Adhem is a Project Manager in the Water Infrastructure service sector at Cole Engineering Group Ltd., Canada. He has over 10 years of experience in process and hydraulic design, as well as construction and project management of water and wastewater treatment facilities in both municipal and industrial applications ranging in capacity from 0.1 to 60 ML/d. Adhem's extensive experience also includes involvement in the design and management of piping and pumping station infrastructure, as well as commercial and residential buildings design and construction. His experience includes working in the USA, Saudi Arabia, United Arab Emirates, Jamaica, and Canada with contractors, consultants, technology manufacturers and suppliers, as well as EPC companies.

Contact Information: Project Manager, Water Infrastructure, Cole Engineering Group Ltd., 70 Valleywood Dr., Markham, Ontario, L3R 4T5, Canada; amukattash@coleengineering.ca