Cost Evaluations for Dredging Projects

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Abstract *— This project was focused on cost evaluations for dredging of five (5) reservoirs in Puerto Rico. These reservoirs were selected because of their importance in Puerto Rico. The cost estimates were made using a disposal site for the whole material, reusing 20% of the dredged material and reusing 50% of the dredged material, a total of three (3) cost estimates were made for each reservoir. The main objective of this research was to show that different alternatives have to be studies in order to make a dredging project. One third of the project cost can be reduced, if the dredged material is used for other purposes.*

Key Terms *— Construction Material, Cost Estimate, Disposal Site, Dredging.*

INTRODUCTION

In the construction industry, one of the principal tasks is the excavation. Excavations can be used to level the terrain to a desire elevation, construction of wells for water structures, or simply for the construction of a building foundation.

Dredging is considered one type of excavation that usually is carried out underwater. It could be done in seas, ports, lakes or river, with the purpose of removing sediments from the bottom. It is used to keep the depth of water at an optimum level. In Puerto Rico, one of the foundations of our progress is the economy. Like all islands, most of the products that the island receives are carried by ships. Therefore it is very important to maintain the water depth navigable at the ports for the success of our economy. The Port of San Juan usually handles between 70 to 80 percent of the cargo entering and leaving the island of Puerto Rico.

The principal supplies of water in Puerto Rico are the reservoirs. During the year 2004, reservoirs contributed with 370 MGD of the raw water entering the plants of the Puerto Rico Aqueduct and Sewer Authority (PRASA) [1]. The sedimentation during the years affects the capacity of the reservoirs, and during time of drought, the potable water service may have problems. Figure 1 shows the location of the reservoirs for the project.

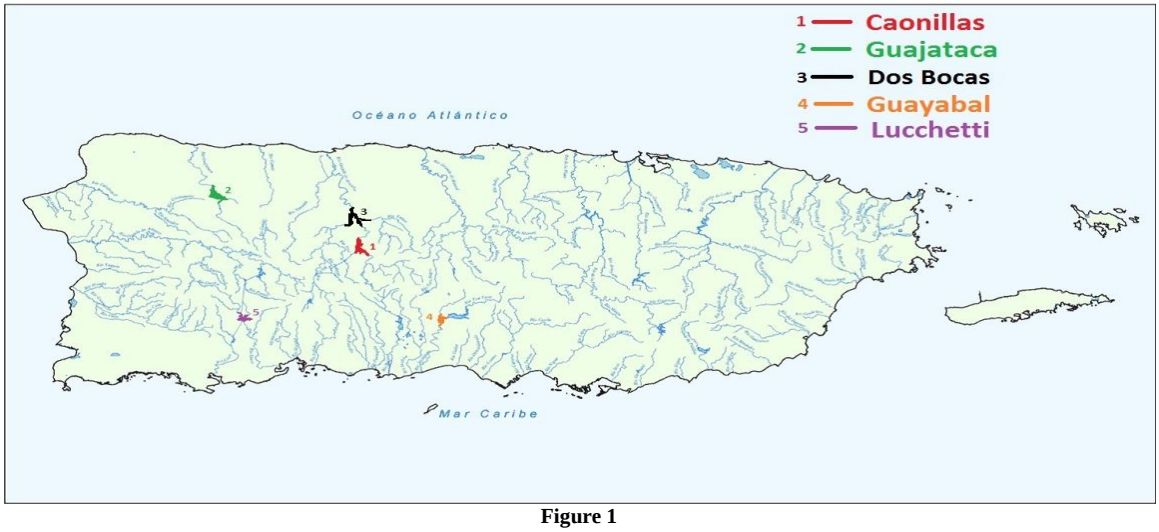

Figure 1
Studied Reservoirs for the Project

It is necessary a sedimentation control program in every lake, river, reservoir or port, in order to control sedimentation problems, and leave dredging as the last alternative because of its cost. If there is no other option and dredging is the chosen alternative it is necessary to have a place for disposal of the dredged material or an alternative for the reuse.

This research will be executed conducting 3 cost estimates for the dredging of the selected reservoirs to restore the storage capacity to the original capacity. One of the estimates will be conducted assuming the 100% disposal of the dredged material. A second estimate will assume that 20% of the material will be reused. The third estimate of cost, will assume a 50/50% condition, 50% will be disposed and the other 50% will be reused. The material that will be reused will be used as a construction material.

The objectives of this research are to show the cost difference between disposing the material or reusing it. Also, it will demonstrate that it is very important to study all alternatives for a dredging project, because dredging is a high cost task.

LITERATURE REVIEW

Located in the Caribbean, Puerto Rico suffers from continuous rainfalls. These rainfalls affect the condition of the rivers and reservoirs. The biggest problem is the sedimentation.

Sedimentation Problems

The combination of high slopes terrains, intense rainfalls and the extensive use of soils, make the erosion rates and sedimentation in Puerto Rico to be higher if we compare it with most areas of the World. The rivers carry the eroded sediments toward the reservoirs where they are trapped. All the reservoirs in the island are losing its storage capacity due to the sedimentation process, but there is much variation in the sedimentation rates between one reservoir to another [1]. The loss on capacity of the reservoirs is shown on Table 1 which shows the original capacity vs. the actual capacity (2004) of the five (5) reservoirs of this study.

Table 1
Reservoirs Original Capacity vs. Actual Storage Capacity

Reservoir	Original Capacity (Mm^3)	Const. year	2004 Estimate Storage Capacity (Mm^3)	Total Vol Loss (Mm^3)	Loss In Percent
Dos Bocas	37.52	1942	16.33	21.19	56
Caonillas	55.66	1948	41.24	14.42	26
Guayabal	11.82	1913	5.94	5.88	50
Guajataca	48.46	1928	41.70	6.76	14
Lucchetti	20.35	1952	10.80	9.55	47
Average					39

As shown, between the five reservoirs there is an average of 39% of loss in capacity, but the Dos Bocas reservoir has lost 56% of its original capacity and Guayabal has lost 50% of its original capacity. A lot can be done with the dredged material taken from these reservoirs. The most economical alternative is the reuse of these materials.

Reuse of Dredged Material

The type of use for the dredged material, depends of what kind of sediment is been taken from the bottom of the reservoir. Depending on what types of sediments it can be used for land creation, topsoil, replacement fill, capping, construction material, etc. Table 2 shows different types of sediments and the beneficial use that can be applies to them.

Table 2
Dredged Material Beneficial Uses

DREDGED MATERIAL BENEFICIAL USES					
Examples of Beneficial Use Activities	Rock	Gravel & Sand	Consolidated Clay	Silt/ Soft Clay	Mixture
Engineering Uses					
Land creation	X	X	X	X	X
Land improvement	X	X	X	X	X
Berm creation	X	X	X		X
Shore protection	X	X	X		
Replacement fill	X	X			X
Beach nourishment		X			
Capping		X	X		X
Construction materials	X	X	X	X	X
Aquaculture			X	X	X
Topsoil				X	X
Wildlife habitats	X	X	X	X	X
Fisheries improvement	X	X	X	X	X
Wetland restoration			X	X	X

The Five Reservoirs

The selection process of these five reservoirs was done using the report "Características y Condición de los Embalses Principales en Puerto Rico" published on March 4, 2004 [2]. This report includes the characteristics and design capacities, actual storage capacities, sedimentation rates, of all reservoirs in Puerto Rico. It also presents the recommendation to restore and improve capacities of those that has critical problems like the following.

- **Caonillas:** This reservoir supplies water to the North coast of Puerto Rico through the North Coast Aqueduct System (NCAS). It has great sedimentation problems. In case of a big rain event, it will be necessary an emergency dredging.
- **Guajataca:** It supplies water to the Northwest towns of Puerto Rico, although its major problem is in the pipelines system. It is necessary to minimize the sedimentation on this watershed. The report does not give an alternative for the sedimentation problems, but for this research it will be assumed the dredging alternative.
- **Dos Bocas:** The area near the dam is having sedimentation problems. These problems put on risk the discharge area of the North Coast Aqueduct, therefore a fast decision has to be taken and dredging is the chosen alternative. More of the 50% of storage capacity has been lost.
- **Guayabal:** The case of this reservoir is even more important, it has lost more than 50% of its design capacity. The south area of the island could have serious problems with the water service.
- **Lucchetti:** The lost on capacity on this reservoir is 47%, this is almost the half of the original capacity. It is necessary a maintenance dredging to improve the conservation of this watershed.

METHODOLOGY

This research analyzed and compared three (3) different cost estimates for the dredging of each of the five (5) chosen reservoirs.

The cost estimates will be assuming 100% disposal of material for estimate one (1), 80% disposal of material for estimate two (2) and a 50/50 condition for estimate three (3). This means one half of the material will be disposed and the other half will be reused.

In order to complete this analysis, the following four (4) tasks were completed.

Task 1. Collect the Data

The first task is to collect the data to evaluate which reservoirs are having sedimentation problems in Puerto Rico. In order to collect this data, the report "Características y Condición de los Embalses Principales en Puerto Rico" [2] will be used.

Task 2. Evaluate the Data

This second task evaluates the data obtained from the report, and proceeds to choose the five (5) reservoirs that are going to be evaluated.

After the reservoirs are chosen, it will be necessary to identify an area where the dredged material will be disposed. The location of this area is very important, because the hauling cost will be greater for a long distance area than for a near area. For the dredged material, it will be assumed a mixture of sand and silt/clay. This type of material can be reused.

Task 3. Prepare the Cost Estimate

The cost estimates for this research will be made in a conceptual stage. For each of the reservoirs, three (3) cost estimates will be made, but some general assumptions has to be made, and listed below.

- **Land Acquisition:** $50,000/Acre
- **Dewatering Area Construction:** $750,000.
- **Environmental Mitigation:** $195,000 from previous dredging projects.

- **Dredging Cost (Hydraulic):** An average of $5.00 from literature review and contractors (mobilization, demobilization and construction of dewatering facility are not included).
- **Hauling Cost:** $9/M^3 according to contractors
- **Disposal Cost:** $14/M^3 according to contractors
- **Mobilization and Demobilization:** $75,000.

Task 4. Analysis and Recommendations

This task is the most important task, because in this section the analysis and the recommendations to get a lower dredging cost for each of the reservoirs will be made.

RESULTS AND DISCUSSION

This part discusses the results and evaluates the cost estimates for each of the selected reservoirs.

Task 1. Collect the Data

After reviewing the report "Características y Condición de los Embalses Principales en Puerto Rico", the reservoirs with the most critical problems were selected. The selected reservoirs were the ones which the storage capacity at this moment is much less than the original design capacity.

Figure 2 shows the actual storage capacity in terms of percentage for the five (5) selected reservoirs.

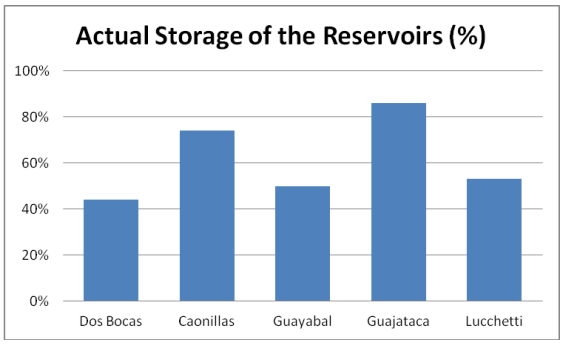

Figure 2
Actual Storage of the Reservoirs (%)

Task 2. Evaluate the Data

At this part of the analysis, the condition of the reservoirs is evaluated. The most important issue is to know the quantity of sediments that needs to be removed from each reservoir. Once the sediment quantities in terms of Cubic Meter (M^3) are found, the next step should be to find a location where the dredged material will be disposed.

The Caonillas Reservoir is located in the town of Utuado, PR (See Figure 3). Its original storage capacity was 55.66 Mm^3 in 1948. Currently, its storage capacity is 41.24 Mm^3, in order to take this reservoir to its original capacity a total of 14.42 Mm^3 of sediment has to be removed. Using the PR-140 along the reservoir, the distance from the reservoir to the disposal area (Hauling Distance) is 5.30 miles.

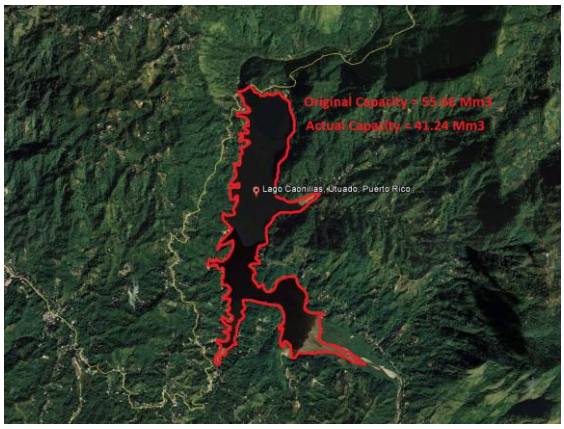

Figure 3
Caonillas Reservoir

The Guajataca Reservoir is located in the borders of the towns of Quebradillas, San Sebastián and Isabela, PR as shown in Figure 4. Its original storage capacity was 48.46 Mm^3 in 1928. Currently, its storage capacity is 41.70 Mm^3, in order to take this reservoir to its original capacity a total of 6.76 Mm^3 of sediment has to be removed. Using the PR-119 along the reservoir, the distance from the reservoir to the disposal area (Hauling Distance) is 5.21 miles.

Figure 4
Guajataca Reservoir

Dos Bocas Reservoir is located in the borders of the cities of Arecibo and Utuado, PR (See Figure 5). Its original storage capacity was 37.52 Mm^3 in 1942. Currently, its storage capacity is 16.33 Mm^3, the quantity of sediment material that has to be removed is 21.19 Mm^3. Using the PR-123 near the reservoir, the distance from the reservoir to the disposal area (Hauling Distance) is 4.45 miles.

Figure 5
Dos Bocas Reservoir

The Guayabal Reservoir, the smallest of the five (5) reservoirs and the oldest one, is located in the borders of the towns of Villalba and Juana Díaz, PR as shown in Figure 6. Its original storage capacity was 11.82 Mm^3 in 1913. Currently, its storage capacity is 5.94 Mm^3, in order to take this reservoir to its original capacity a total of 5.88 Mm^3 of sediments needs to be removed. Using the PR-149 along the reservoir, the distance from the reservoir to the disposal area (Hauling Distance) is 7.09 miles.

Figure 6
Guayabal Reservoir

Lucchetti Reservoir is located in the town of Yauco, PR (See Figure 7). Its original storage capacity was 20.35 Mm^3 in 1952. Currently, its storage capacity is 10.80 Mm^3, the quantity of sediment material that has to be removed is 9.55 Mm^3. Using the PR-128, PR-127 and PR-121, the distance from the reservoir to the disposal area (Hauling Distance) is 8.61 miles.

Figure 7
Lucchetti Reservoir

Task 3. Prepare the Cost Estimate

Once the volume quantities that needed to be removed are known, the next step in this research is to prepare the conceptual cost estimates for the five (5) reservoirs.

- **Caonillas:** This is a major reservoir in Puerto Rico; therefore the quantity of sediment in this reservoir is 14,420,000 M^3. As shown on Table 3, if all the material will be disposed, the cost of the project will be $537,225,000. But if just 20% of this dredged material is going to be

reused, as a construction material, land creation, topsoil, the cost of the project will be $480,505,000 which is a reduction of $56,720,000 or 11% less than the original cost. The last alternative, a 50% of the material will be disposed and 50% will be reused, with this alternative the total cost of the project will be $395,425,000. This is a 27% reduction of the cost if all material was disposed.

Table 3
Cost Estimate Comparison for Caonillas Reservoir

Caonillas Reservoir					
	Quantity	Unit	Item	Unit Cost	0% Reused Cost
1	1	LS	Dewatering Area Construction	$750,000.00	$750,000.00
2	1	LS	Environmental Mitigation	$195,000.00	$195,000.00
3	14,420,000	CM	Dredging (Hydraulic)	$5.00	$72,100,000.00
4	500	Acre	Disposal Land Acquisition	$50,000.00	$25,000,000.00
5	0	CM	Hauling for Reused Material	$9.00	$0.00
6	14,420,000	CM	Hauling and Disposal Cost for Dredged Material	$23.00	$331,660,000.00
7	1	LS	Mobilization and Demobilization	$75,000.00	$75,000.00
8			Sub-Total		$429,780,000.00
9			Contingencies		$107,445,000.00
10			**Total Cost**		**$537,225,000.00**
	Quantity	Unit	Item	Unit Cost	20% Reused Cost
1	1	LS	Dewatering Area Construction	$750,000.00	$750,000.00
2	1	LS	Environmental Mitigation	$195,000.00	$195,000.00
3	14,420,000	CM	Dredging (Hydraulic)	$5.00	$72,100,000.00
4	400	Acre	Disposal Land Acquisition	$50,000.00	$20,000,000.00
5	2,884,000	CM	Hauling for Reused Material	$9.00	$25,956,000.00
6	11,536,000	CM	Hauling and Disposal Cost for Dredged Material	$23.00	$265,328,000.00
7	1	LS	Mobilization and Demobilization	$75,000.00	$75,000.00
8			Sub-Total		$384,404,000.00
9			Contingencies		$96,101,000.00
10			**Total Cost**		**$480,505,000.00**
	Quantity	Unit	Item	Unit Cost	50% Reused Cost
1	1	LS	Dewatering Area Construction	$750,000.00	$750,000.00
2	1	LS	Environmental Mitigation	$195,000.00	$195,000.00
3	14,420,000	CM	Dredging (Hydraulic)	$5.00	$72,100,000.00
4	250	Acre	Disposal Land Acquisition	$50,000.00	$12,500,000.00
5	7,210,000	CM	Hauling for Reused Material	$9.00	$64,890,000.00
6	7,210,000	CM	Hauling and Disposal Cost for Dredged Material	$23.00	$165,830,000.00
7	1	LS	Mobilization and Demobilization	$75,000.00	$75,000.00
8			Sub-Total		$316,340,000.00
9			Contingencies		$79,085,000.00
10			**Total Cost**		**$395,425,000.00**

- **Guajataca:** This is the most important reservoir in the West-Central part of Puerto Rico; the quantity of dredged material in this one is 6,760,000 M^3. Tables show that if all the material will be disposed, the cost of the project will be $253,812,500. The second estimate presents the cost estimate for a 20% reused material and 80% disposed, with this alternative the cost of the project will be $226,965,000 which is a reduction of $26,847,500. The last alternative, a 50% of the material will be disposed and 50% will be reused. The total cost of the project will be $186,725,000. If a better place for the disposal site for this project is found, the cost will be much less. Table 4 shows the detail cost estimate for this dredging project.

Table 4
Cost Estimate Comparison for Guajataca Reservoir

Guajataca Reservoir					
	Quantity	Unit	Item	Unit Cost	0% Reused Cost
1	1	LS	Dewatering Area Construction	$750,000.00	$750,000.00
2	1	LS	Environmental Mitigation	$195,000.00	$195,000.00
3	6,760,000	CM	Dredging (Hydraulic)	$5.00	$33,800,000.00
4	255	Acre	Disposal Land Acquisition	$50,000.00	$12,750,000.00
5	0	CM	Hauling for Reused Material	$9.00	$0.00
6	6,760,000	CM	Hauling and Disposal Cost for Dredged Material	$23.00	$155,480,000.00
7	1	LS	Mobilization and Demobilization	$75,000.00	$75,000.00
8			Sub-Total		$203,050,000.00
9			Contingencies		$50,762,500.00
10			**Total Cost**		**$253,812,500.00**
	Quantity	Unit	Item	Unit Cost	20% Reused Cost
1	1	LS	Dewatering Area Construction	$750,000.00	$750,000.00
2	1	LS	Environmental Mitigation	$195,000.00	$195,000.00
3	6,760,000	CM	Dredging (Hydraulic)	$5.00	$33,800,000.00
4	204	Acre	Disposal Land Acquisition	$50,000.00	$10,200,000.00
5	1,352,000	CM	Hauling for Reused Material	$9.00	$12,168,000.00
6	5,408,000	CM	Hauling and Disposal Cost for Dredged Material	$23.00	$124,384,000.00
7	1	LS	Mobilization and Demobilization	$75,000.00	$75,000.00
8			Sub-Total		$181,572,000.00
9			Contingencies		$45,393,000.00
10			**Total Cost**		**$226,965,000.00**
	Quantity	Unit	Item	Unit Cost	50% Reused Cost
1	1	LS	Dewatering Area Construction	$750,000.00	$750,000.00
2	1	LS	Environmental Mitigation	$195,000.00	$195,000.00
3	6,760,000	CM	Dredging (Hydraulic)	$5.00	$33,800,000.00
4	128	Acre	Disposal Land Acquisition	$50,000.00	$6,400,000.00
5	3,380,000	CM	Hauling for Reused Material	$9.00	$30,420,000.00
6	3,380,000	CM	Hauling and Disposal Cost for Dredged Material	$23.00	$77,740,000.00
7	1	LS	Mobilization and Demobilization	$75,000.00	$75,000.00
8			Sub-Total		$149,380,000.00
9			Contingencies		$37,345,000.00
10			**Total Cost**		**$186,725,000.00**

- **Dos Bocas:** This is not the biggest of the reservoirs studied in this research; but the sedimentation problem in this one is very critical. Dos Bocas has lost 56% of its design capacity. The quantity of sediment that needs to be removed from this reservoir to take it to its original capacity is 21,190,000 M^3. As shown on Table 5, the first alternative, if all the material will be disposed, the cost of the project will be $780,425,000 which is a high cost project. But if 20% of these sediments are going to be reused, as a construction material, land creation, topsoil, the cost of the project will be $698,760,000 which is a reduction of $81,665,000 of the original cost. The last alternative, a 50% of the material will be disposed and 50% will be reused, with this alternative the total cost of the project will be $576,262,500, less than $200,000,000 of the first estimate, where all the material was disposed.

Table 5
Cost Estimate Comparison for Dos Bocas Reservoir

Dos Bocas Reservoir					
	Quantity	Unit	Item	Unit Cost	0% Reused Cost
1	1	LS	Dewatering Area Construction	$750,000.00	$750,000.00
2	1	LS	Environmental Mitigation	$195,000.00	$195,000.00
3	21,190,000	CM	Dredging (Hydraulic)	$5.00	$105,950,000.00
4	600	Acre	Disposal Land Acquisition	$50,000.00	$30,000,000.00
5	0	CM	Hauling for Reused Material	$9.00	$0.00
6	21,190,000	CM	Hauling and Disposal Cost for Dredged Material	$23.00	$487,370,000.00
7	1	LS	Mobilization and Demobilization	$75,000.00	$75,000.00
8			Sub-Total		$624,340,000.00
9			Contingencies		$156,085,000.00
10			**Total Cost**		**$780,425,000.00**
	Quantity	Unit	Item	Unit Cost	20% Reused Cost
1	1	LS	Dewatering Area Construction	$750,000.00	$750,000.00
2	1	LS	Environmental Mitigation	$195,000.00	$195,000.00
3	21,190,000	CM	Dredging (Hydraulic)	$5.00	$105,950,000.00
4	480	Acre	Disposal Land Acquisition	$50,000.00	$24,000,000.00
5	4,238,000	CM	Hauling for Reused Material	$9.00	$38,142,000.00
6	16,952,000	CM	Hauling and Disposal Cost for Dredged Material	$23.00	$389,896,000.00
7	1	LS	Mobilization and Demobilization	$75,000.00	$75,000.00
8			Sub-Total		$559,008,000.00
9			Contingencies		$139,752,000.00
10			**Total Cost**		**$698,760,000.00**
	Quantity	Unit	Item	Unit Cost	50% Reused Cost
1	1	LS	Dewatering Area Construction	$750,000.00	$750,000.00
2	1	LS	Environmental Mitigation	$195,000.00	$195,000.00
3	21,190,000	CM	Dredging (Hydraulic)	$5.00	$105,950,000.00
4	300	Acre	Disposal Land Acquisition	$50,000.00	$15,000,000.00
5	10,595,000	CM	Hauling for Reused Material	$9.00	$95,355,000.00
6	10,595,000	CM	Hauling and Disposal Cost for Dredged Material	$23.00	$243,685,000.00
7	1	LS	Mobilization and Demobilization	$75,000.00	$75,000.00
8			Sub-Total		$461,010,000.00
9			Contingencies		$115,252,500.00
10			**Total Cost**		**$576,262,500.00**

- **Guayabal:** This is smallest of the reservoirs studied in this research; but the sedimentation here is a big problem. Guayabal has lost 50% of its design capacity. The quantity of sediment that needs to be removed from this reservoir to take it to its original capacity is 5,880,000 M^3. In Table 6, the first alternative, if all the material will be disposed, the cost of the project will be $222,700,000. If 20% of these sediments are going to be reused, the cost of the project will be $198,995,000 which is a reduction of $23,705,000 of the original cost. The last alternative, a 50% of the material will be disposed and 50% will be reused, with this alternative the total cost of the project will be $166,562,500, which is less than $56,000,000 of the first estimate, where all the material was disposed. The case of this reservoir is critical, because it's the smallest one, but it has lost 50% of storage capacity. This could affect the water distribution service in the area.

Table 6
Cost Estimate Comparison for Guayabal Reservoir

Guayabal Reservoir					
	Quantity	Unit	Item	Unit Cost	0% Reused Cost
1	1	LS	Dewatering Area Construction	$750,000.00	$750,000.00
2	1	LS	Environmental Mitigation	$195,000.00	$195,000.00
3	5,880,000	CM	Dredging (Hydraulic)	$5.00	$29,400,000.00
4	250	Acre	Disposal Land Acquisition	$50,000.00	$12,500,000.00
5	0	CM	Hauling for Reused Material	$9.00	$0.00
6	5,880,000	CM	Hauling and Disposal Cost for Dredged Material	$23.00	$135,240,000.00
7	1	LS	Mobilization and Demobilization	$75,000.00	$75,000.00
8			Sub-Total		$178,160,000.00
9			Contingencies		$44,540,000.00
10			**Total Cost**		**$222,700,000.00**
	Quantity	Unit	Item	Unit Cost	20% Reused Cost
1	1	LS	Dewatering Area Construction	$750,000.00	$750,000.00
2	1	LS	Environmental Mitigation	$195,000.00	$195,000.00
3	5,880,000	CM	Dredging (Hydraulic)	$5.00	$29,400,000.00
4	200	Acre	Disposal Land Acquisition	$50,000.00	$10,000,000.00
5	1,176,000	CM	Hauling for Reused Material	$9.00	$10,584,000.00
6	4,704,000	CM	Hauling and Disposal Cost for Dredged Material	$23.00	$108,192,000.00
7	1	LS	Mobilization and Demobilization	$75,000.00	$75,000.00
8			Sub-Total		$159,196,000.00
9			Contingencies		$39,799,000.00
10			**Total Cost**		**$198,995,000.00**
	Quantity	Unit	Item	Unit Cost	50% Reused Cost
1	1	LS	Dewatering Area Construction	$750,000.00	$750,000.00
2	1	LS	Environmental Mitigation	$195,000.00	$195,000.00
3	5,880,000	CM	Dredging (Hydraulic)	$5.00	$29,400,000.00
4	175	Acre	Disposal Land Acquisition	$50,000.00	$8,750,000.00
5	2,940,000	CM	Hauling for Reused Material	$9.00	$26,460,000.00
6	2,940,000	CM	Hauling and Disposal Cost for Dredged Material	$23.00	$67,620,000.00
7	1	LS	Mobilization and Demobilization	$75,000.00	$75,000.00
8			Sub-Total		$133,250,000.00
9			Contingencies		$33,312,500.00
10			**Total Cost**		**$166,562,500.00**

- **Lucchetti:** This is a medium size reservoir; the sedimentation here is another big issue. Lucchetti has lost 47% of its original storage capacity. The quantity of sediment that needs to be removed from this reservoir to take it to its original capacity is 9,550,000 M^3. In Table 7, the first alternative, if all the material will be disposed, the cost of the project will be $354,275,000. If 20% of these sediments are going to be reused, the cost of the project will be $317,100,000 which is a reduction of $37,175,000 of the original cost. The last alternative, a 50% of the material will be disposed and 50% will be reused, with this alternative the total cost of the project will be $261,337,500, which is more than $92,000,000 of the first estimate, where all the material was disposed. This reservoir should be dredged soon, because like Guayabal, the actual capacity of this reservoir is almost a half of the original design capacity of 1952 when it was constructed.

Table 7
Cost Estimate Comparison for Lucchetti Reservoir

Lucchetti Reservoir					
	Quantity	Unit	Item	Unit Cost	0% Reused Cost
1	1	LS	Dewatering Area Construction	$750,000.00	$750,000.00
2	1	LS	Environmental Mitigation	$195,000.00	$195,000.00
3	9,550,000	CM	Dredging (Hydraulic)	$5.00	$47,750,000.00
4	300	Acre	Disposal Land Acquisition	$50,000.00	$15,000,000.00
5	0	CM	Hauling for Reused Material	$9.00	$0.00
6	9,550,000	CM	Hauling and Disposal Cost for Dredged Material	$23.00	$219,650,000.00
7	1	LS	Mobilization and Demobilization	$75,000.00	$75,000.00
8			Sub-Total		$283,420,000.00
9			Contingencies		$70,855,000.00
10			**Total Cost**		**$354,275,000.00**
	Quantity	Unit	Item	Unit Cost	20% Reused Cost
1	1	LS	Dewatering Area Construction	$750,000.00	$750,000.00
2	1	LS	Environmental Mitigation	$195,000.00	$195,000.00
3	9,550,000	CM	Dredging (Hydraulic)	$5.00	$47,750,000.00
4	240	Acre	Disposal Land Acquisition	$50,000.00	$12,000,000.00
5	1,910,000	CM	Hauling for Reused Material	$9.00	$17,190,000.00
6	7,640,000	CM	Hauling and Disposal Cost for Dredged Material	$23.00	$175,720,000.00
7	1	LS	Mobilization and Demobilization	$75,000.00	$75,000.00
8			Sub-Total		$253,680,000.00
9			Contingencies		$63,420,000.00
10			**Total Cost**		**$317,100,000.00**
	Quantity	Unit	Item	Unit Cost	50% Reused Cost
1	1	LS	Dewatering Area Construction	$750,000.00	$750,000.00
2	1	LS	Environmental Mitigation	$195,000.00	$195,000.00
3	9,550,000	CM	Dredging (Hydraulic)	$5.00	$47,750,000.00
4	150	Acre	Disposal Land Acquisition	$50,000.00	$7,500,000.00
5	4,775,000	CM	Hauling for Reused Material	$9.00	$42,975,000.00
6	4,775,000	CM	Hauling and Disposal Cost for Dredged Material	$23.00	$109,825,000.00
7	1	LS	Mobilization and Demobilization	$75,000.00	$75,000.00
8			Sub-Total		$209,070,000.00
9			Contingencies		$52,267,500.00
10			**Total Cost**		**$261,337,500.00**

Task 4. Analysis and Recommendations

After the cost estimates were made, it is clear that the dredging process is a very expensive alternative but it is the most effective.

In the cases of Caonillas and Dos Bocas, there is too much sediment in the depth of the lakes. Therefore it's too expensive to do it in one step, but these two (2) reservoirs are very important part of the Puerto Rico Aqueduct System, it has to be dredged. One of the recommendations is to make these dredging projects, maintenance projects, for 15-25 years, and the cost will be lower if it is paid annually and not at present time. The best alternative will be, not to dredge the entire reservoirs, but just the areas were the sedimentation problems are critical and affect the water service. If the dredged material can be sold to a construction company, the cost will be much lower. In Puerto Rico there are many contractors who buy these kinds of materials.

In Guayabal and Lucchetti, the sedimentation quantities in these two (2) reservoirs are lower than the other ones, but the lost in capacity is bigger than the other ones. In this cases a dredging project of 4 to 9 years, can achieved good results. In these cases the alternative of dredging a special area of the reservoir could be justified but not recommended, because of the lost in storage capacity.

In the Guajataca Reservoir, the dredging of this reservoir after the analysis is not necessary. First it is an expensive alternative, and the quantity of sediment that needs to be removed from the depth is minimal compared to the original capacity. This reservoir has only lost 14% of its original capacity. A maintenance project can be made here, like mitigation, control measures, among others, that will be cheaper than dredging.

CONCLUSION

This research demonstrated the importance of evaluating all the alternatives when sedimentation problems occur. Dredging is one of the most expensive alternatives, for this is necessary to find the best alternative in order to reduce the cost impact in a project. In four (4) of this five (5) reservoirs, if all the material is going to be disposed, it will be 27% percent more expensive than if the material is reused. In Puerto Rico there are many places and contractors who buy this dredged material for construction material uses, or as a fill material. In Puerto Rico, the reservoirs have to be designed, for a long life. Preventive maintenance has to be made, it is cheaper than dredging.

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