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Suspended Particulate Matter in Rivers and Estuaries

Particulate matter transport in the proposed Sea Level Canal, Panama

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With 11 figures and 4 tables

Abstract: The existing Panama Lock Canal system which commenced operation in 1914, allowing ships to travel between the Pacific and the Atlantic oceans, may be reaching its capacity. One of the alternatives that was proposed to this canal system is the Sea Level canal, Route 10. The principal maintenance problem in the sea level canal is sedimentation. This paper analyzes the physical processes which contribute to sedimentation in the sea level canal and reports the annual sedimentation rates estimated using mathematical models LATIS and ROUTES. The estimated annual sedimentation rate of 450,000 m^3 with the use of these models compared well with the field data obtained from the existing canal.

Introduction

One of the most fascinating engineering achievements of the twentieth century is the construction of the Panama Canal linking the Atlantic Ocean and the Pacific Ocean. The canal was opened for traffic on August 14, 1914, and has never been closed since then. However, during the last several decades there have been significant increases in the volume of traffic and in the size of ships. To meet the increase in traffic and to accommodate larger ships, transportation planners and engineers have been studying the feasibility of constructing another canal linking the two Oceans. One of the options proposed was the construction of a Sea Level Canal, similar to the Suez Canal in the Middle East, parallel to the existing lock canal.

The Sea Level Canal Option was one of the future alternatives investigated for the study, Operating Characteristics and Capacity Evaluation (OCCE) Study sponsored by the Commission for the Study of Alternatives to the Panama Canal. The study commission was formed by the governments of Panama, the United States, and Japan. The basic purpose of the OCCE study was to evaluate the traffic capacities of various canal alternatives. The scope of work included the estimation of currents generated by the tides in the sea level canal and the estimation of sedimentation in the sea level canal. This paper summarizes and documents the methodology used to study the movement of particulate matter that causes sedimentation and quantifies the amount of particulate matter that may settle in the proposed sea level canal.

The emphasis is on the application of the existing theories to the motion of particulate matter in the canal and the uncertainties associated with them, rather than on developing new theories. In this paper, particulate matter includes all kinds of inorganic granular materials that are transported by water and which can settle either in the canal, or in the ocean. However, it does not include any biological matter. This study to quantify the particulate matter in the canal was necessary because of the enormous costs incurred in maintaining navigation canals, predominantly by dredging. A brief description of the study area in section 2 identifies the geographical location and other physical details. In Section 3, a summary of the hydraulic studies that led to the selection of the sea level canal with a tide gate is discussed. Section 4 is the main body of the paper where several topics are explained. The various physical processes

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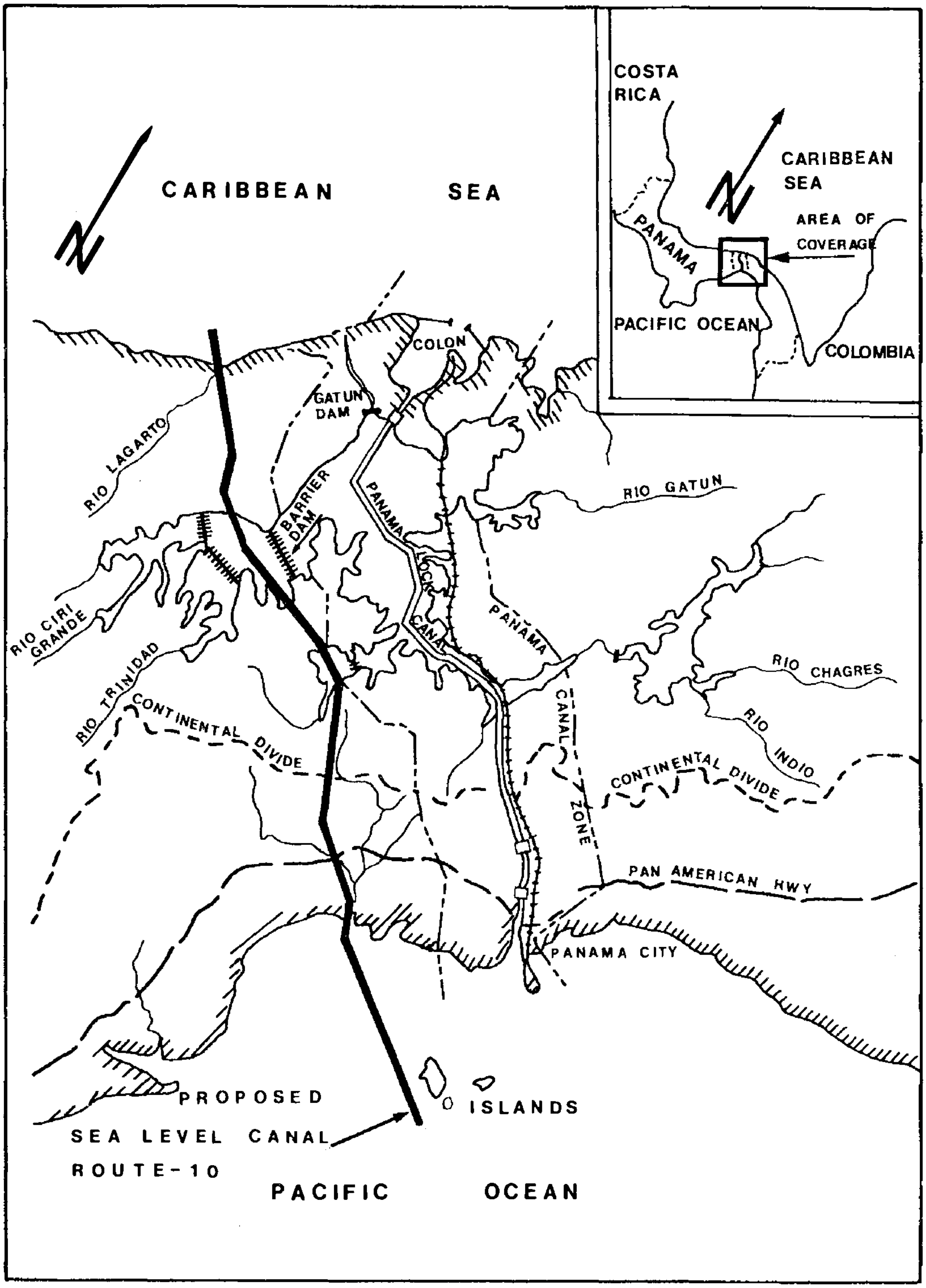
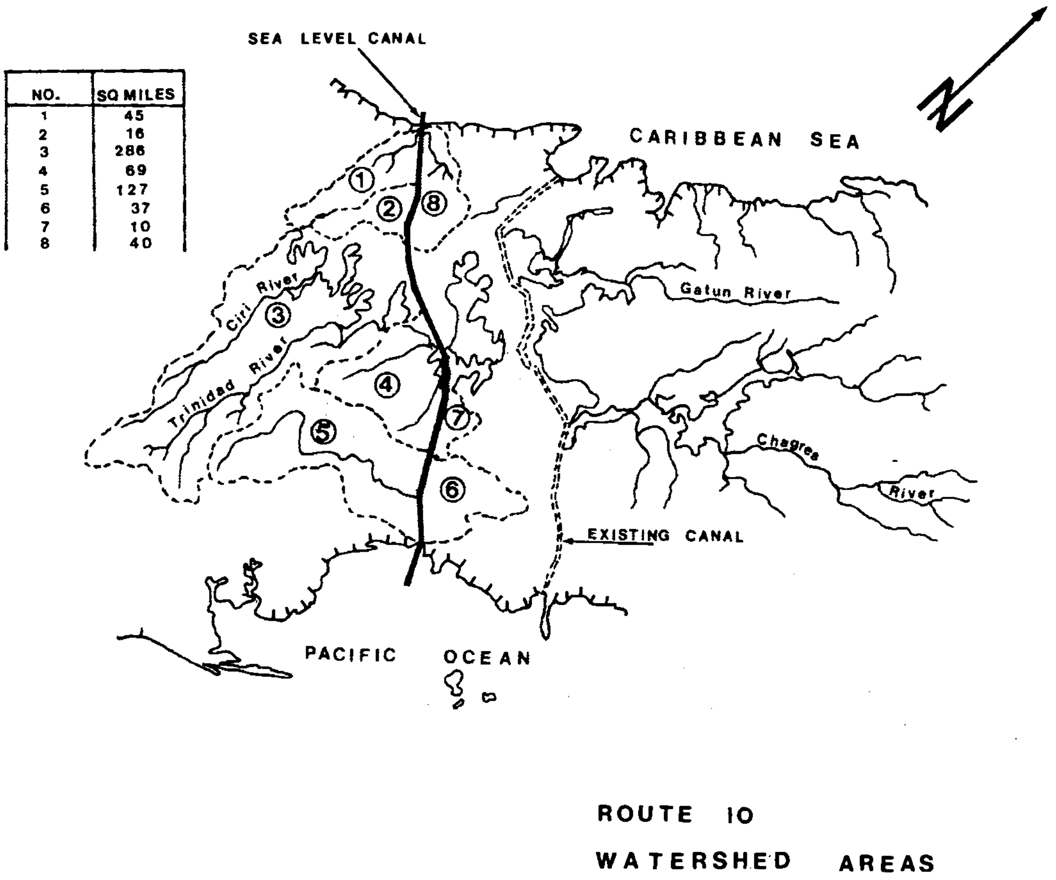


Fig. 1. Physical layout of the canal system.

that have to be considered in quantifying the amount of particulate matter are described. The idealization of the project and the modelling methodology are also elaborated. Typical results are then presented. As the model results are subject to uncertainty, a sensitivity analysis was carried out and is narrated in Section 5. The summary and conclusions in Section 6 completes the paper.



NO.	SQ MILES
1	45
2	16
3	286
4	69
5	127
6	37
7	10
8	40

Fig. 2. Watershed area.

Study Area

The layout of the existing canal and the proposed canal are illustrated in Fig. 1. It would be located, approximately, 15 km south east of the existing canal. Due to the peculiar geological formation of Panama, contrary to the common belief that the Atlantic Ocean is to the right and the Pacific Ocean is to the left of the countries in the continent of America, the Atlantic Ocean is shown on the left and the Pacific Ocean is shown on the right of the land formation of Panama.

The proposed canal is 60.8 km long, shore to shore. It passes through Gatun Lake and intersects several streams and rivers. The total catchment area that would be draining into the canal is 1700 sq.km, out of which 470 sq.km would be draining into the Pacific Ocean while 1230 sq.km. would be draining into the Atlantic Ocean. The different drainage areas are identified in Fig. 2. The transoceanic canal studies (3) identified fifteen major rivers that would intercept the canal. The rivers, their catchment areas, the invert levels, and the bank on which the streams will intercept the canal are tabulated in Table 1. These rivers or streams would be entering the canal at various elevations. A longitudinal section of the canal, Fig. 3, illustrates the different invert levels of the streams that will intersect the canal.

Hydraulic studies

As the safe navigation of ships is dependent on the speed of water in the restricted canal, it was necessary to study the effect of the various canal configurations on the speed of water. Several configurations were investigated. The largest ship that is expected to travel is 300,000 DWT,

Table 1. Rivers intercepting route 10.

No.	Name	Drainage Area (Sq.Miles)	Invert EL(MSL)	Bank	Dist.in Km From Atlantic
1	Lagarto	45.0	0.0	W	1.54
2	Arrieros	34.0	0.0	E	1.54
3	Quebrada La Escoba	3.5	15.0	E	9.26
4	Quebrada Brazito	16.0	15.0	W	13.88
5	Trinidad & Ciri	288.0	30.0	W	20.05
6	Los Azules	32.1	70.0	W	32.39
7	Quebrada De Chico	4.2	70.0	W	34.71
8	Mendoza	3.7	60.0	W	36.25
9	Cano Quebrada	28.6	70.0	W	38.56
10	Pescado	8.5	70.0	E	39.33
11	Santa Cruz	2.2	95.0	W	44.73
12	Congo	2.8	250.0	E	49.05
13	Caimito I	115.5	30.0	W	54.00
14	Martin Sanchez	11.4	0.0	W	60.16
15	Caimito II	47.0	0.0	E	60.93

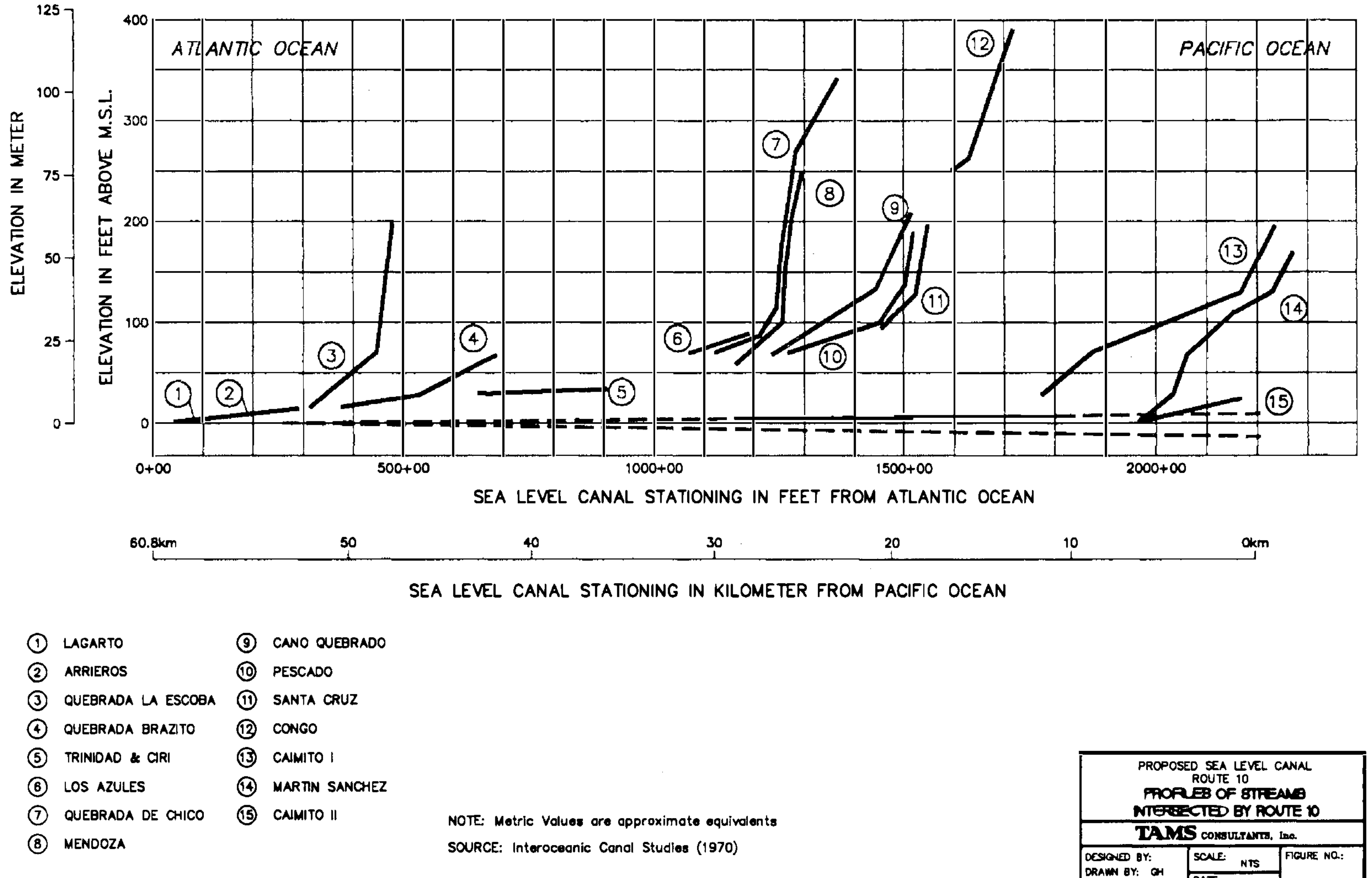
and the size is 394 m long with a beam of 61 m and a draft of 23 m. Based on the guidelines specified by the client, the Commission for Study of alternatives for the Panama Canal, the bed width and the depth of the canal have to be at least 183 m and 25.3 m, respectively, for a single lane canal. Assuming a trapezoidal section, the minimum bottom widths adopted for the canal are 190 m and 425 m, respectively, for the single lane and two lane canals.

Having determined the preliminary dimensions of the canal, the next step is to determine the flow velocities in the canal that would result from the tides in the Pacific Ocean and the Atlantic Ocean. The two approaches to estimate the flow velocities in the shipping canal are physical modelling and mathematical modelling. At the planning stages of a project, numerical models are cheaper than physical models; the mathematical models are quicker; and the results are reliable and serve the purpose. Therefore, a numerical modelling approach was used to determine the flow velocities in the canal for the different configurations that were studied.

The mathematical program used for the study, LATIS, is a link-node model. This computer program resolves the vertically integrated equations of motion in an open channel with an explicit finite difference scheme. A basic layout of the link-node system is illustrated in Fig. 4. The program computes the water surface elevations at the nodes and the velocities along the links at each and every time step. The basic data requirement for the model are canal properties, such as, the conveyance, the cross-sectional area, the depth, and the width; node volumes at specified depths; and tide elevations in the Atlantic and Pacific Oceans. A detailed description of the model can be found in References 1 and 2.

The trace of the canal, Fig. 1, shows a minimum of eight deviations requiring transition curves. The flow patterns occurring in the curved reaches have been neglected and the canal has been assumed to be a straight one, 60.8 km long. It has been represented by 21 nodes and 20 links. Although the canal will pass through different geological formations having different roughness coefficients, it has been assumed that an average value of 0.025 for Manning's roughness coefficient will be a representative value for the roughness of the entire canal. It has been further assumed that the tributary inflows are negligible.

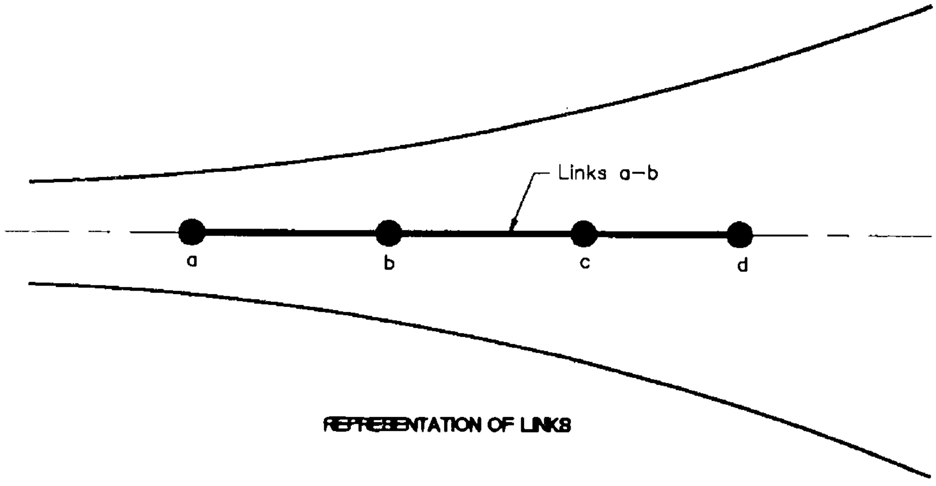
The physical process causing the flow of water in the canal is the tide in the Pacific (Balboa) and the Atlantic (Cristobal) Oceans. The predicted tides for the two oceans during the



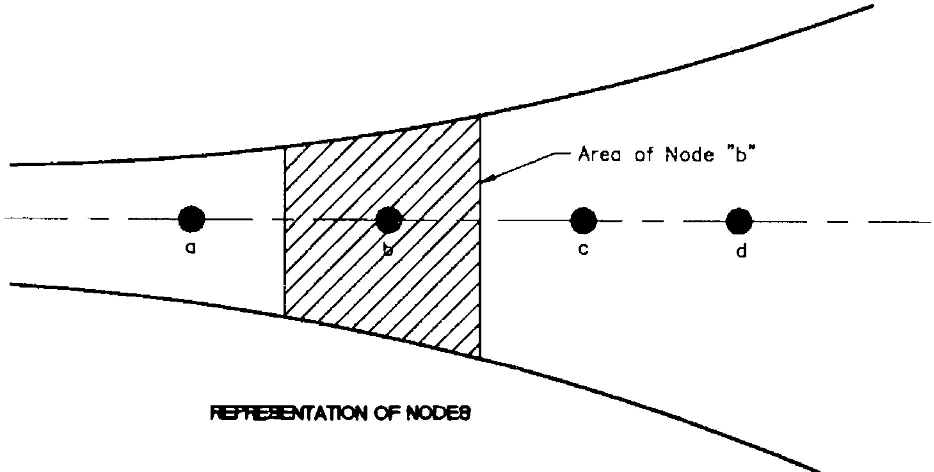
NOTE: Metric Values are approximate equivalents

SOURCE: Interoceanic Canal Studies (1970)

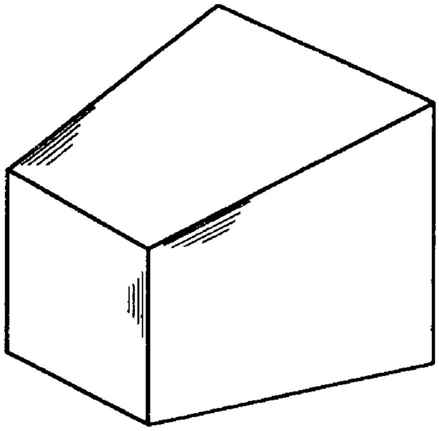
Fig. 3. Longitudinal section of canal.



REPRESENTATION OF LINKS



REPRESENTATION OF NODES

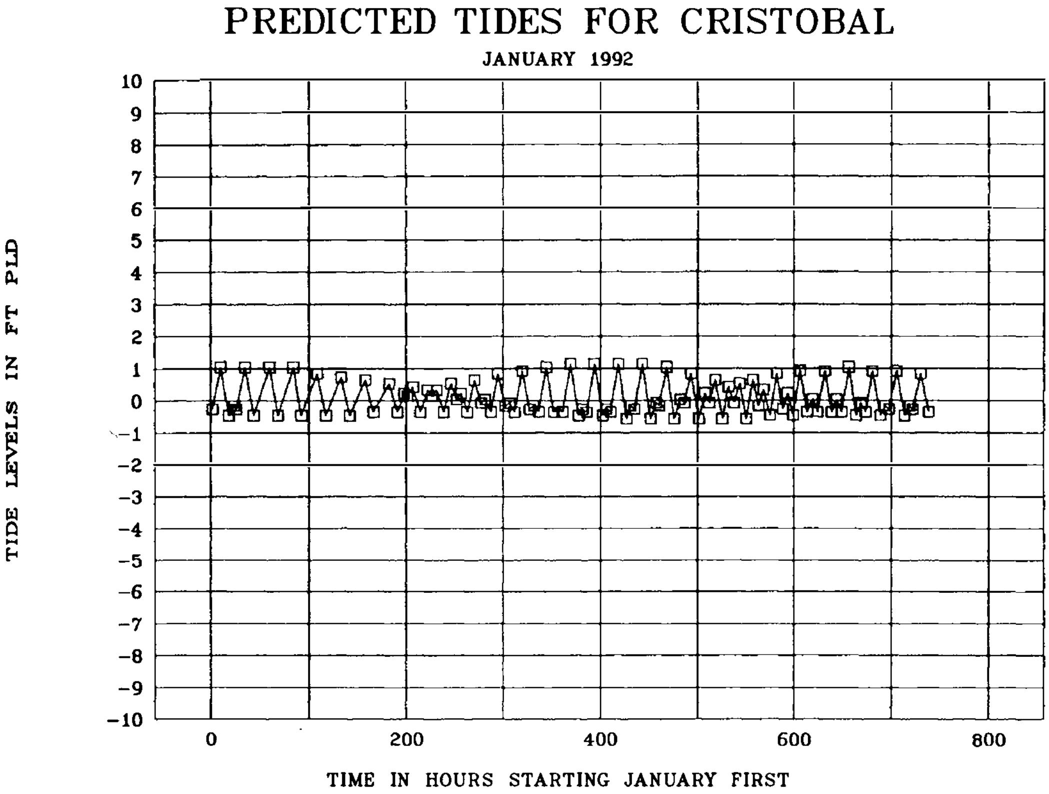


VOLUME OF NODE 'b'

Fig. 4. Model links and nodes.

month of January 1992 are illustrated in Fig. 5. The water speeds in the canal will be very high during spring tide in the Pacific Ocean, and it was decided to simulate the flows in the canal for this tide situation.

Initially, a few trial runs had to be made to choose the appropriate time interval for numerical computation. The model was able to run with a simulation time of 50 seconds. As can be seen from the results, numerical stability is achieved within 3 tidal cycles. Seven alternatives for the sea level canal were investigated and the results for one of the alternatives,



PREDICTED TIDES FOR BALBOA

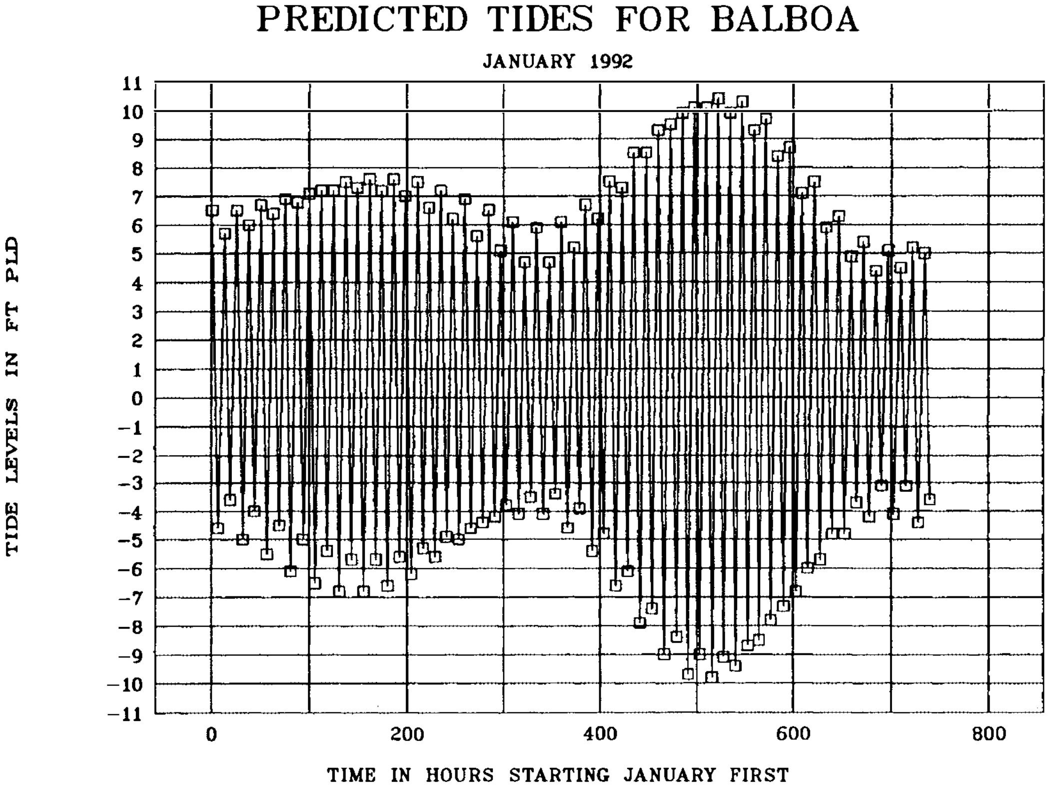


Fig. 5. Pacific and Atlantic tides.

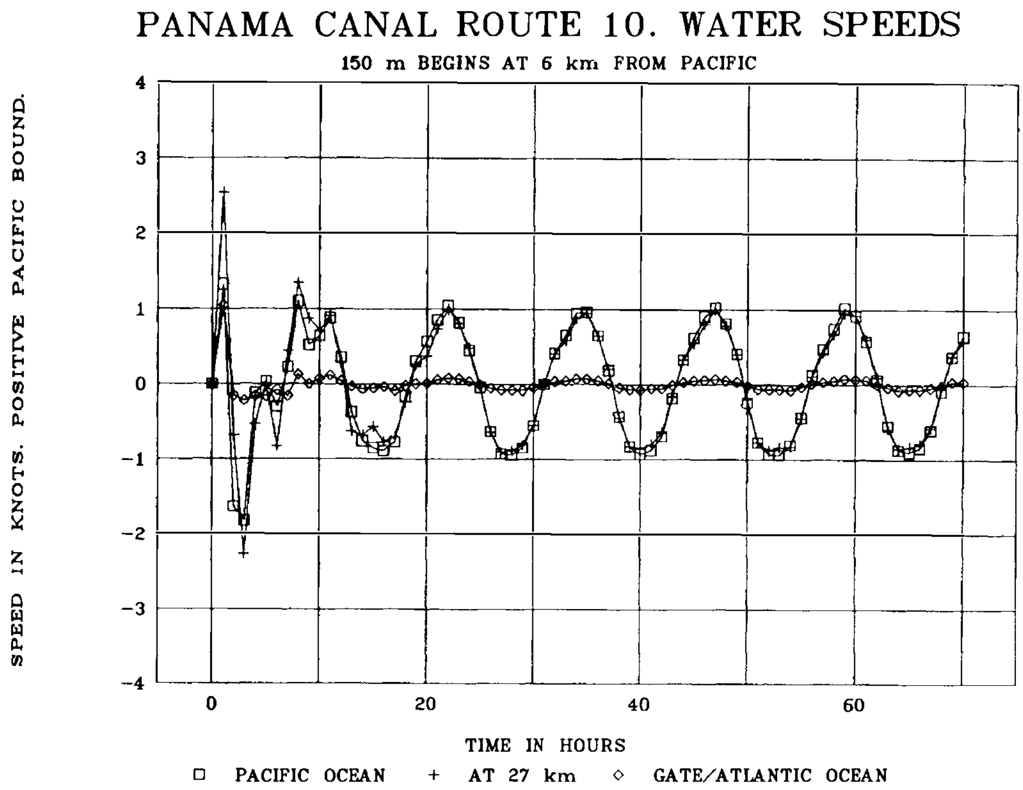


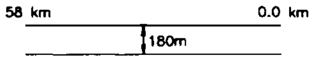
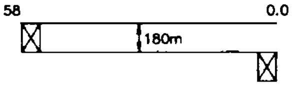
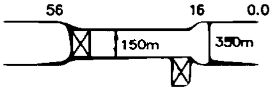
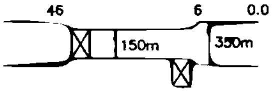
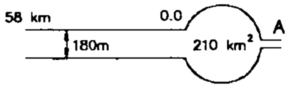
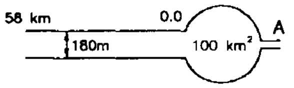
Fig. 6. Model predictions – water speed in canal.

the tide gate alternative, is illustrated in Fig. 6. One can see from the figure that the velocity in the ultimate link, near the gate, is either very close to zero, or zero. This is to be expected because of the closed gate through which water will not flow. For comparison of water speeds, the results for all of the alternatives are summarized in Table 2. One could see from this table that the water speeds are reduced and the maximum water speeds approach 1 knot for the case where the tide gate is 6 km from the Pacific end.

A detailed description of the various alternatives are the subject of a companion paper and are not discussed here. However, for completeness, a brief summary in the next paragraph states the reasons for choosing a tide gate canal for detailed analysis.

The first two configurations investigated in the analysis cannot be adopted, because of the very high water speeds. It will be difficult to manoeuvre the ships at such speeds. Although the water speeds are reduced for the alternative 3, the speeds are still higher than 2 knots, the limiting speed for navigation. Intuitively one may feel that alternatives 6 and 7 should reduce the water speeds. However, the water speeds in the canal are still high due to the tidal range in the Pacific. Further, the water speed at the entrance is 17 and 9 knots, respectively, for the basins 200 km^2 and 100 km^2. The high water speeds at the entrance will cause severe erosion and will be a hindrance for navigation. Alternatives 4 and 5 are the suitable candidates. However, from the viewpoint of cost, configuration 5 is cheaper than configuration 4 due to reduced canal excavation. Therefore, configuration 4, which has a 40 km single lane canal with two lane approaches with tide gates, and the tide gate on the Pacific side which is located at 6 km from the shore line, was chosen as the preferred alternative for further studies.

Table 2. Results of LATIS analysis.

CASE TESTED	CONFIGURATION OF CANAL (Atlantic End – Pacific End)	ELEVATION OF BOTTOM AT PACIFIC END	MAX. WATER SPEED (Knots)			
			58 km	36 km	0.0 km	A
① WITHOUT GATES		−28.7m	5.2	4.2	4.0	-
② WITHOUT GATES		−28.7m	5.5	4.7	4.2	-
③ GATES AT 58 & 0.0 Km		−28.7m	0.2	1.3	2.2	-
④ GATES AT 56 & 16 Km		−24.5m	*0.4	1.0	1.5	-
⑤ GATES AT 46 & 6 Km		−24.5m	0.0	**1.0	1.0	-
⑥ VERGARA ALTER. I		−28.7m	4.3	3.3	3.1	17
⑦ VERGARA ALTER. II		−28.7m	4.7	3.9	3.4	9

All of the results refer to the spring tide situation. Manning's Number = 0.025, which is a measure of channel roughness.

* Max. water speed refers to a location 56 km from the Pacific entrance.

** Max. water speed refers to a location 27.0 km from the Pacific entrance.

Particulate matter transport

General

Once the best alternative for navigation was chosen, it was necessary to address other factors such as berthing of ships and dredging. For safe navigation, breakwaters were provided at the Pacific entrance and at the Atlantic entrance. These structural modifications alter the flow characteristics in the canal. They also alter the movement of particulate matter in the canal, at the entrances to the canal, and along the shoreline. The main impact of particulate movement on the project is the cost of dredging. Therefore, particulate transport studies were also included to estimate the quantity of sediment that will be deposited in the canal zone, namely, the canal, the entrances to the canal, and the coast adjoining the breakwaters. However, the details and results provided in this paper are limited to the stretch of the canal extending from the breakwater entrance at the Pacific to the breakwater entrance at the Atlantic. It neither describes the changes at the entrances nor the changes along the shore line.

The movement of particulate matter in the canal is controlled by several factors. The tides in the Atlantic and Pacific, the flows in the streams intersected by the canal, the physical,

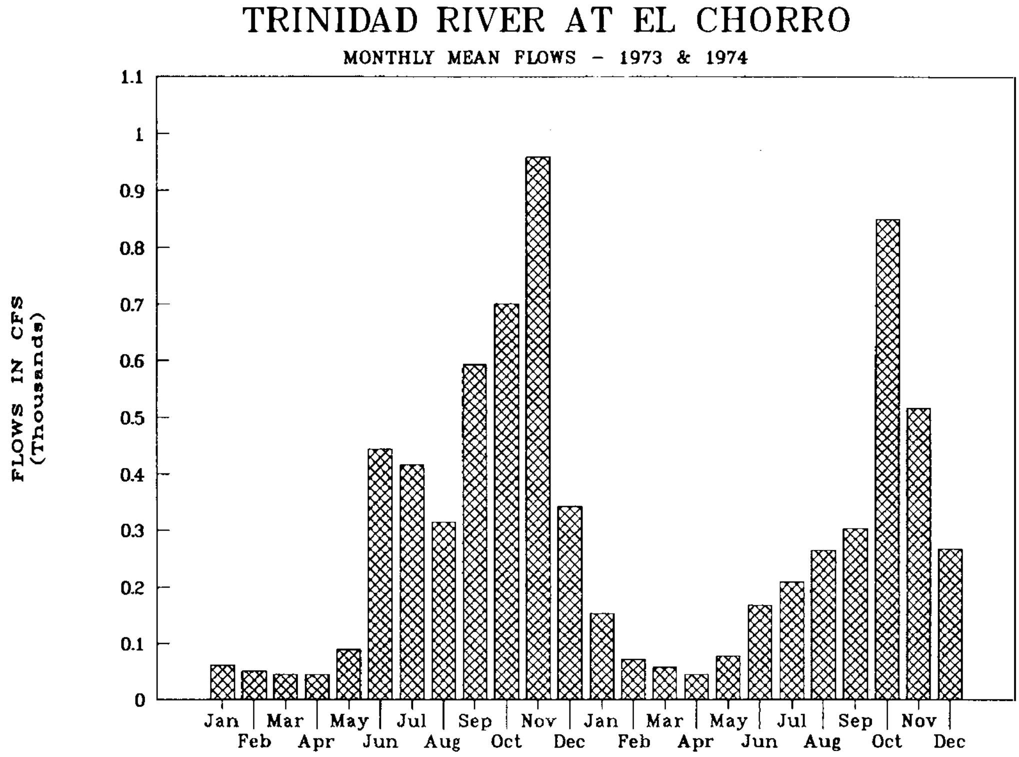


Fig. 7. Flow in Trinidad River at El Chorro.

chemical, and physico-chemical characteristics of the particulate matter and the fluid, the nature of the terrain through which the canal passes, the operation of the tide gates, and the movement of ships, are some of the primary factors that control the movement of particles. These factors vary both in time and space. The flow in the canal may have either a one-dimensional, or a two-dimensional, or a three-dimensional flow pattern. In general, the flow pattern in the canal is one-dimensional, flowing either towards the Pacific, or towards the Atlantic. However, at the confluences of streams with the canal, the flow is two-dimensional and the flow is three-dimensional at the Atlantic entrance and the Pacific entrance of the canal. In such a complex situation, how could one characterize the movement of particulate matter and quantify the amount that would settle in the canal? Another complicating factor is that there aren't any field measurements. Field measurements are not available as the canal has not been built.

Physical processes

River discharge and sediment movement

As described in Section 2, fifteen rivers intercept the proposed canal. Although the flows from these rivers were neglected in the hydraulic analysis in choosing a suitable canal configuration, the flows are primary sources of particulate matter in the canal. It can be shown theoretically that the quantities of sediment transported into the canal by these streams are dependent on their flows. The flows are not constant and have a seasonal pattern as illustrated in Fig. 7, where the monthly flows for the Trinidad River, one of the rivers that would be intercepting the canal, are shown for the years 1973 and 1974. One would expect a similar cycle in the quantity of particulate matter discharged into the canal.

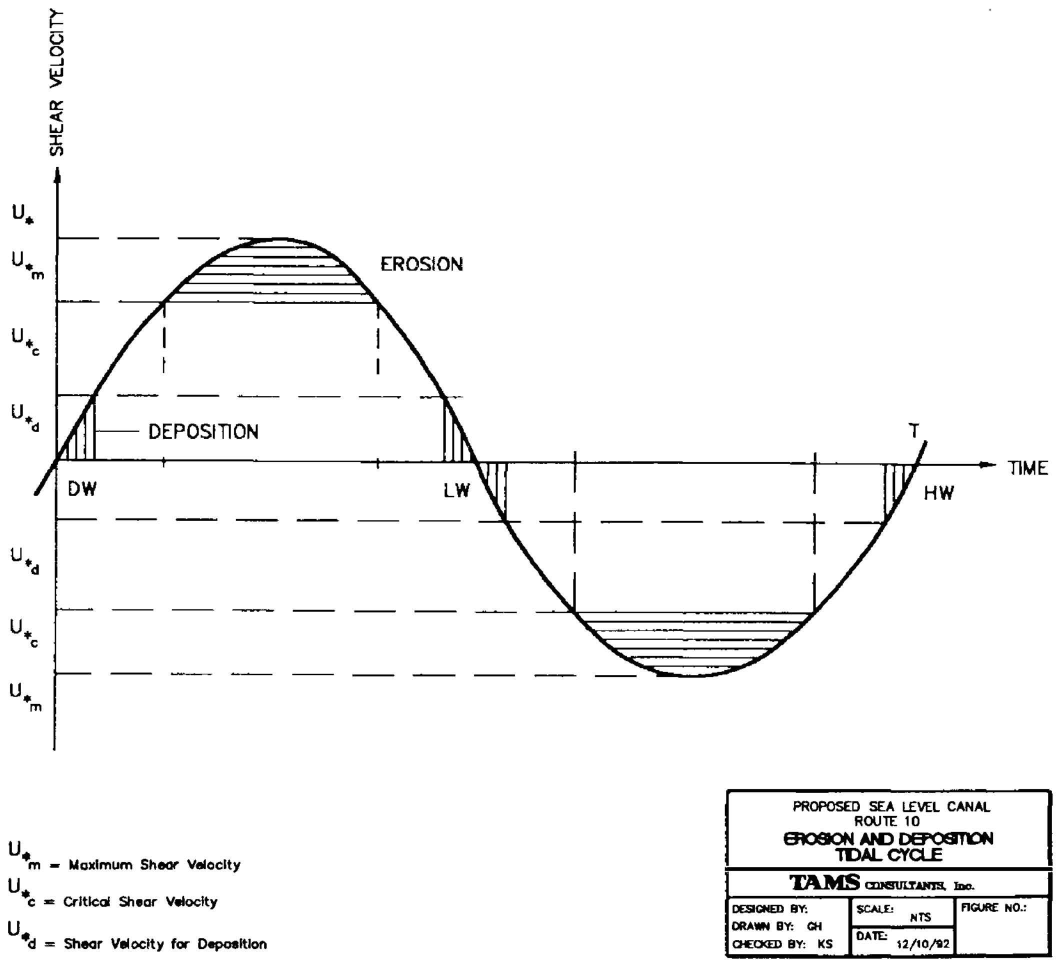


Fig. 8. Erosion and deposition – tidal cycle (4).

Tides and sediment transport

The different patterns of the tides in the Atlantic and the Pacific were illustrated in Fig. 5. The daily and fortnightly cycles are consistent in the Pacific ocean, whereas they are rather random and chaotic in the Atlantic ocean. A similar pattern could be expected for the velocity, which causes the movement of particles. An idealized version of particle movement during a tidal cycle is shown in Fig. 8. It shows that erosion takes place when the velocity exceeds a critical value and that deposition takes place when the velocity falls below a certain value. It also shows a region where neither erosion, nor deposition takes place.

Breakwaters and littoral drift

Breakwaters have been proposed at the entrances to prevent siltation of the canal entrances and to protect ships from strong winds. The tidal currents and wave action influence the movement of particles. However, the movement of particles due to the interaction of waves and currents has not been accounted for this paper.

Land use pattern and land slides

Changes in the existing land use practices may also increase sedimentation in the canal. One such practice is the slash and burn agricultural technique practised by the farmers. This has eliminated the forests along the existing canal increasing erosion in the watershed and siltation in the existing canal. Such a phenomenon may occur in the proposed canal. Land slides are another source of sediment which can be prevented by proper land management practices.

Summary

In addition to the above physical processes, the operation of gates and ship generated waves are some other factors which have to be taken into account. Therefore, the particle movement in the canal is influenced by several factors, namely, river discharge, ocean tides, waves, interaction of waves and currents, land use pattern, and ship generated waves.

Methodoloy

Once again a mathematical modelling technique was used to estimate the annual sedimentation in the canal. Two programs, LATIS and ROUTES, were used for this part of the study. The program LATIS generates the necessary hydrodynamic input data for ROUTES, in the appropriate format. However, additional data such as the period of simulation, the physical properties, and the composition of sediment have to be provided in a separate data file. At the end of the simulation the program provides a summary containing a list of nodes and the total depth of sedimentation at each node during the simulation period. As for LATIS the details of program ROUTES can be found in Reference 5.

Description of the scheme

A pictorial view of the canal with the breakwaters and the tide gates is given in Fig. 9. The two gates are located at 6 km and 46 km from the Pacific shore. The gate closer to the Pacific shore is referred to as the south gate and the gate closer to the Atlantic is referred to as the North gate. On the Pacific side, the breakwaters extend to a length of 10 km. However, the breakwaters on the Atlantic side are shorter, 3.5 km long.

The approach canals from the oceans are double lane, 400 m wide, while the 40 km single lane stretch is 190 m wide. The inflows from thirteen rivers are shown to enter the canal, while the flows from Trinidad and Ciri are omitted. The flows from these two rivers have been omitted because the stretch of the canal through Gatun lake will be diked. To simplify the modelling exercise further, the canal bed and the side slopes have been assumed to be stable. The real time operating characteristics of the gates have been taken into account in an approximate manner.

Idealization of the scheme

The study area consisting of the canal and the breakwaters was represented by 25 links and 26 nodes. The breakwaters on the Atlantic side were represented by two links, 225–224 and 224–20, and the breakwaters on the Pacific side were represented by four links as shown in Fig. 10. The rivers flowing into the canal were represented by links and are listed in Table 3. To simplify the effect of opening and closing of the tide gates, two sets of simulations were carried out. For one set of simulations, it was assumed that the tide gate at the Atlantic side, North gate, is closed, while the one at the Pacific side is open so that the Pacific tide controls the movement of particles. For the other set of simulations, it was assumed that the tide gate at the Pacific side, South gate is closed, while the one at the Atlantic side is open so that the Atlantic tide influences the movement of particles.

Several physical conditions have to be taken into account and the line diagram in Fig. 11 shows the several combinations that were considered.

(a) To take into account the diurnal variation and the spring/neap cycle, the predicted tide for the month of January 1992 was simulated.

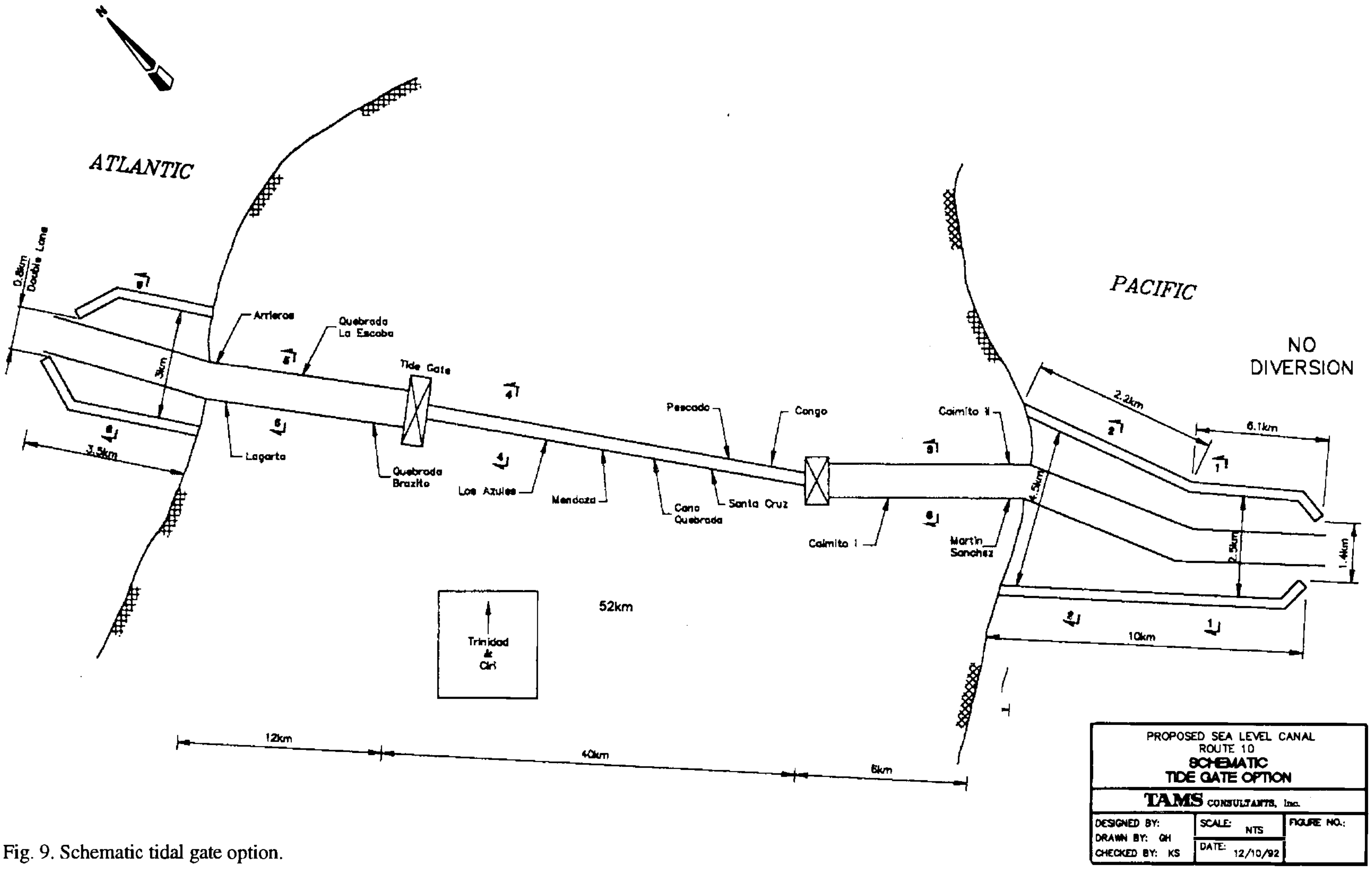


Fig. 9. Schematic tidal gate option.

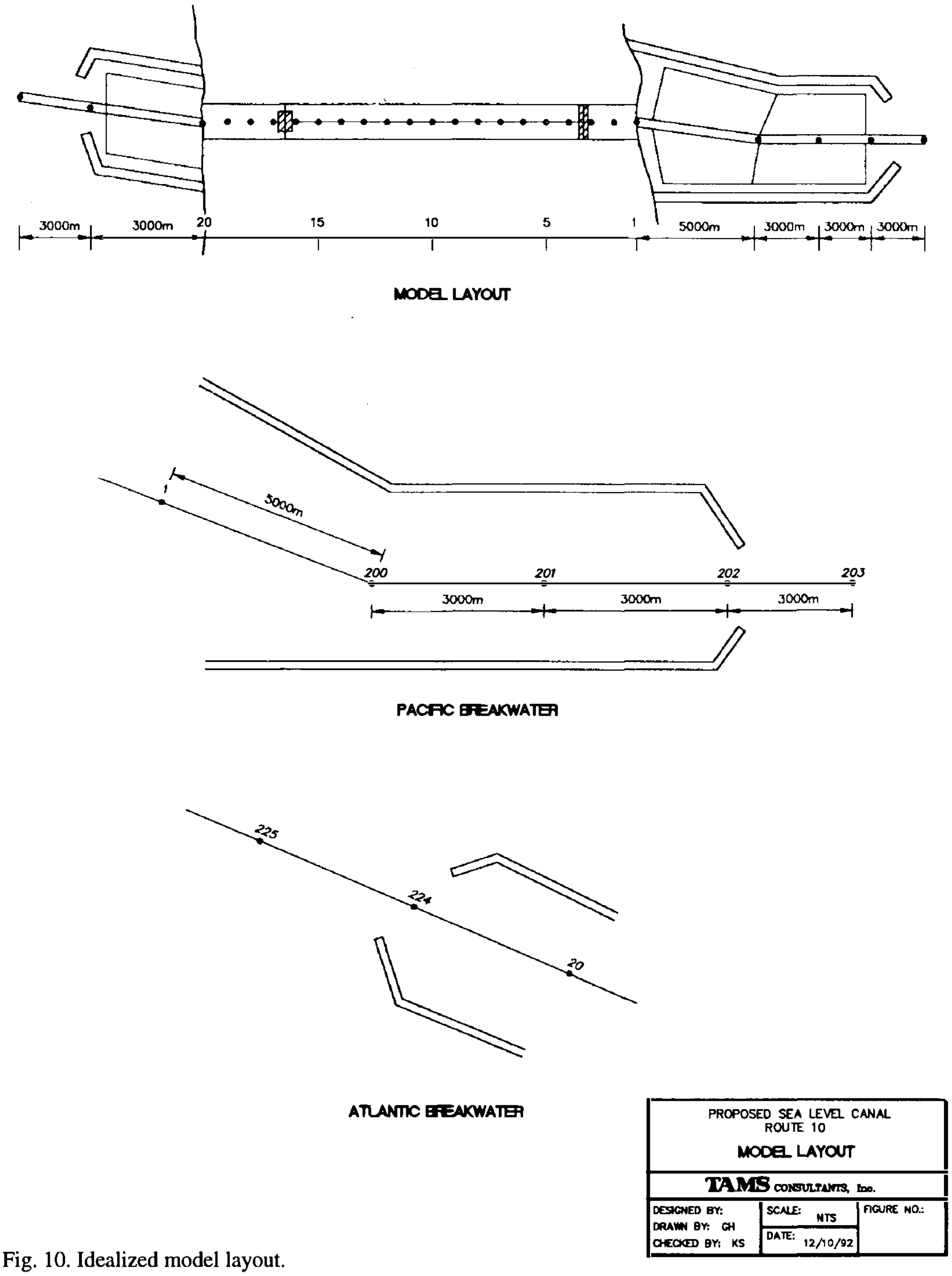


Fig. 10. Idealized model layout.

(b) To incorporate the changing flows in the rivers that intercept the canal, three flow conditions, maximum, mean, and minimum, were simulated.

(c) To assess the effects due to the type of sediments, coarse sand, fine sand, and clay were analyzed.

(d) Finally, as the sedimentation depths will vary depending on the concentration of sediments in the river flows, three values, 5000 mg/l, 2000 mg/l, and 100 mg/l, were used in the simulation.

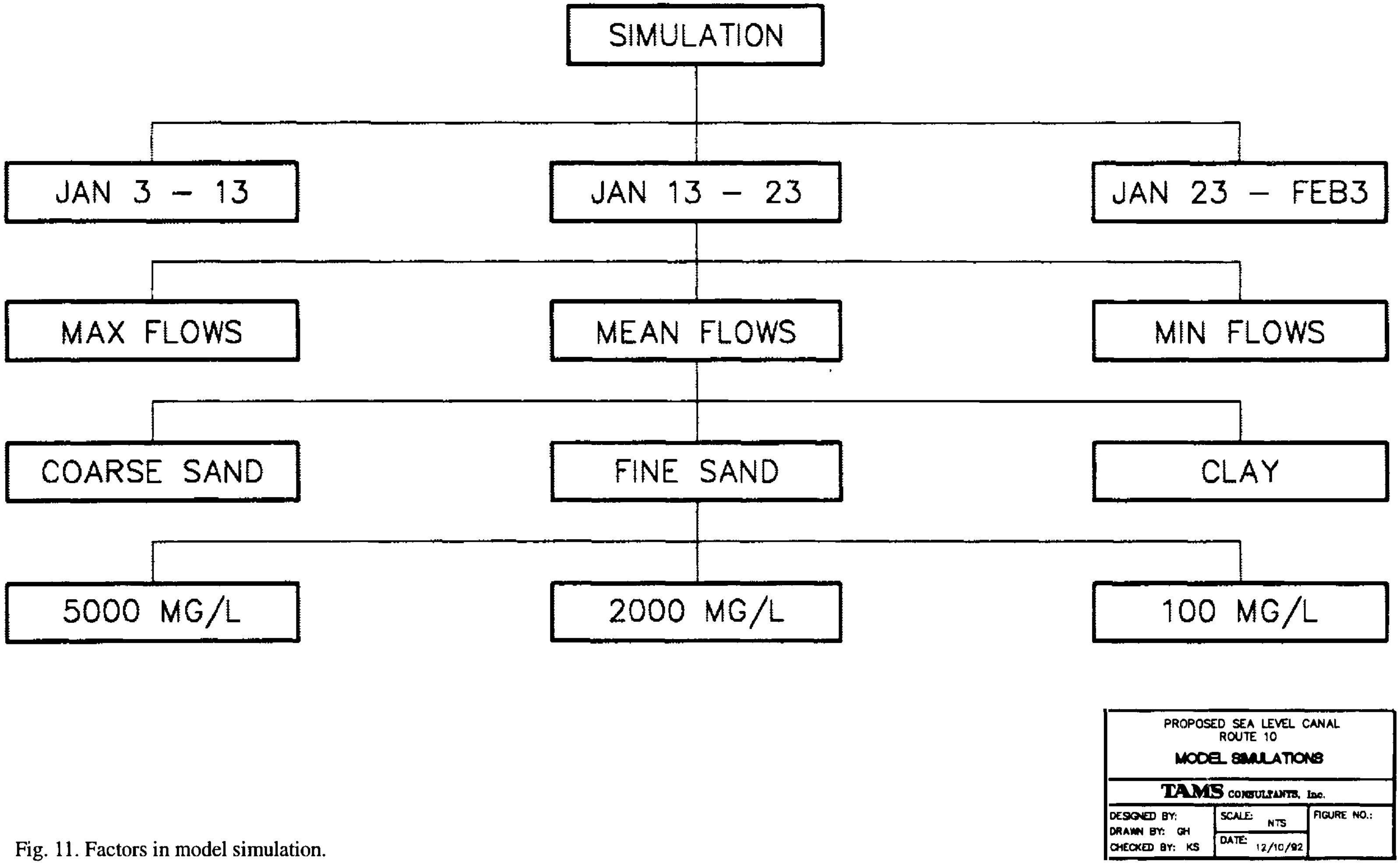


Fig. 11. Factors in model simulation.

Table 3. Panama Canal flows in rivers.

No.	Name	Bank	Link	Max^m Flows(cfs)
1	Caimito II	E	101-1	282
2	Martin Sanchez	W	102-1	68
3	Caimito I	W	103-3	693
4	Congo	E	104-5	17
5	Santa Cruz	W	105-6	12
6	Pescado	E	106-8	51
7	Cano Quebrado	W	107-8	172
8	Mondoza	W	108-9	22
9	Quebrada De Chico	W	109-10	25
10	Los Azules	W	110-11	193
11	Trinidad & Ciri	W	111-15	1,728
12	Quebrada Brazito	W	112-17	96
13	Quebrada La Escoba	E	113-18	21
14	Arrieros	E	114-20	204
15	Lagarto	W	115-20	270

Model results

The hydrodynamic model LATIS had to be completely re-run for the sediment investigations because of providing breakwaters at the entrances. However, the results from the hydrodynamic simulations are not presented in this part of the paper, as sediment deposition is the topic of interest. To illustrate the range of sedimentation depths in the canal, the results for the condition where the North gate is closed with maximum flows in the rivers, and sediment composition being coarse sand is shown in Table 4.

Bases on the various simulations that were carried out, the following broad conclusions were made.

(a) When the South gate is closed and the sediment composition is sand, the depth of deposition varies from 0.5 cm to 16 cm along the canal per year for the different nodes.

(b) When the North gate is closed and the sediment composition is sand, the depth of deposition varies from 0.5 cm to 100 cm along the canal per year for the different nodes.

(c) When the South gate is closed and the sediment composition is clay, the depth of deposition varies from 0.0 cm to 5 cm along the canal per year for the different nodes.

(d) When the North gate is closed and the sediment composition is clay, the depth of deposition varies fom 0.0 cm to 5 cm along the canal per year for the different nodes.

Averaging the depth of sedimentation at the various nodes, an annual sedimentation of 450,000 m^3 was estimated.

Conclusion

The models, which are idealizations of the physical process, give estimates which have to be interpreted with extreme care and caution. This is due to the assumptions that are inherent in the entire modelling procedure, namely, the input data, the boundary conditions, the values assigned to the parameters, and the numerical scheme used in the algorithm. A main feature in the scheme is that the canal is yet to be built and data are not available. Hence, an added necessity of caution in interpreting the value of 450,000 m^3/yr of annual sedimentation.

Table 4. Panama Canal – north gate closed sedimentation depths (feet).

<table>
<tr><th colspan="4">SEDIMENT CONCENTRATION 100 MG/L</th></tr>
<tr><th>NODE</th><th>295 HOUR</th><th>60 HOUR</th><th>CHANGE</th></tr>
<tr><td>3</td><td>0.0007</td><td>0.0001</td><td>0.0006</td></tr>
<tr><td>8</td><td>0.0003</td><td>0.0000</td><td>0.0003</td></tr>
<tr><td>11</td><td>0.0003</td><td>0.0000</td><td>0.0003</td></tr>
<tr><td>200</td><td>0.0002</td><td>0.0000</td><td>0.0002</td></tr>
<tr><td>202</td><td>0.0001</td><td>0.0000</td><td>0.0001</td></tr>
<tr><th colspan="4">SEDIMENT CONCENTRATION 2,000 MG/L</th></tr>
<tr><td>1</td><td>0.0012</td><td>0.0002</td><td>0.0010</td></tr>
<tr><td>2</td><td>0.0007</td><td>0.0001</td><td>0.0006</td></tr>
<tr><td>3</td><td>0.0132</td><td>0.0027</td><td>0.0105</td></tr>
<tr><td>4</td><td>0.0010</td><td>0.0002</td><td>0.0008</td></tr>
<tr><td>5</td><td>0.0007</td><td>0.0001</td><td>0.0006</td></tr>
<tr><td>6</td><td>0.0004</td><td>0.0000</td><td>0.0004</td></tr>
<tr><td>7</td><td>0.0004</td><td>0.0000</td><td>0.0004</td></tr>
<tr><td>8</td><td>0.0062</td><td>0.0013</td><td>0.0049</td></tr>
<tr><td>9</td><td>0.0014</td><td>0.0002</td><td>0.0012</td></tr>
<tr><td>10</td><td>0.0046</td><td>0.0003</td><td>0.0043</td></tr>
<tr><td>11</td><td>0.0899</td><td>0.0046</td><td>0.0853</td></tr>
<tr><td>12</td><td>0.0033</td><td>0.0001</td><td>0.0032</td></tr>
<tr><td>13</td><td>0.0002</td><td>0.0000</td><td>0.0002</td></tr>
<tr><td>15</td><td>0.0008</td><td>0.0002</td><td>0.0006</td></tr>
<tr><td>200</td><td>0.0033</td><td>0.0007</td><td>0.0026</td></tr>
<tr><td>201</td><td>0.0009</td><td>0.0002</td><td>0.0007</td></tr>
<tr><td>202</td><td>0.0024</td><td>0.0005</td><td>0.0019</td></tr>
<tr><th colspan="4">SEDIMENT CONCENTRATION 5,000 MG/L</th></tr>
<tr><th>NODE</th><th>295 HOUR</th><th>60 HOUR</th><th>CHANGE</th></tr>
<tr><td>1</td><td>0.0031</td><td>0.0006</td><td>0.0025</td></tr>
<tr><td>2</td><td>0.0018</td><td>0.0003</td><td>0.0015</td></tr>
<tr><td>3</td><td>0.0330</td><td>0.0067</td><td>0.0263</td></tr>
<tr><td>4</td><td>0.0026</td><td>0.0005</td><td>0.0021</td></tr>
<tr><td>5</td><td>0.0017</td><td>0.0003</td><td>0.0014</td></tr>
<tr><td>6</td><td>0.0011</td><td>0.0002</td><td>0.0009</td></tr>
<tr><td>7</td><td>0.0010</td><td>0.0002</td><td>0.0008</td></tr>
<tr><td>8</td><td>0.0154</td><td>0.0031</td><td>0.0123</td></tr>
<tr><td>9</td><td>0.0025</td><td>0.0005</td><td>0.0020</td></tr>
<tr><td>10</td><td>0.0020</td><td>0.0004</td><td>0.0016</td></tr>
<tr><td>11</td><td>0.0139</td><td>0.0028</td><td>0.0111</td></tr>
<tr><td>12</td><td>0.0005</td><td>0.0001</td><td>0.0004</td></tr>
<tr><td>15</td><td>0.0019</td><td>0.0004</td><td>0.0015</td></tr>
<tr><td>200</td><td>0.0084</td><td>0.0017</td><td>0.0067</td></tr>
<tr><td>201</td><td>0.0021</td><td>0.0004</td><td>0.0017</td></tr>
<tr><td>202</td><td>0.0060</td><td>0.0012</td><td>0.0048</td></tr>
</table>

Verification of results

As the model predictions were based on several assumptions and approximations, one method by which the results could be checked is to obtain field measurements of sedimentation. However, in this particular case, the canal has not been built and data do not exist. Therefore, it was decided to estimate the annual sedimentation for the existing canal, based on bathymetric surveys, and compare the estimated values with the results of the mathematical model prediction. By this way one could ascertain the order of magnitude difference between the model predicted value and the measured value at the existing canal.

It was possible to obtain bathymetric data for the present canal on two dates. The canal had not been dredged during the intervening period. The change in bathymetry during this measurement period would indicate either erosion or deposition. Extrapolating the field data from the existing canal, for a single lane 190 m wide canal, sedimentation values varied from 551,000 m^3/yr to 742,000 m^3/yr. A mean value of 660,000 m^3/yr can be assessed for the proposed canal. When you compare the 660,000 m^3/yr with a value of 450,000 m^3/yr, the estimate from the model predictions, 450,000 m^3/yr for the proposed canal, is an acceptable result.

Summary and conclusions

A hydro-dynamic model LATIS was used to choose a suitable configuration for the proposed sea level canal in Panama. The best layout consisted of a 40 km long and 190 m wide single lane canal with tide gates at the ends, together with double lane approaches at the Atlantic side and the Pacific side. A particle transport model, ROUTES, was used to estimate the settling of particles in the entire canal. The model predicted value for the settled particles is 450,000 m^3/yr. An assessment of the field data for the existing canal indicated an annual settling rate in the range of 551,000 m^3/yr to 742,000 m^3/yr. Although the model predicted value for the proposed canal appears to be lower than the extrapolated value from the bathymetric data for the existing canal, the predicted value of 450,000 m^3/yr is an acceptable value for the purpose of costing annual dredging. This value can be modified once the canal is constructed and is in operation when field data will be available!

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