Phase 1 Final Design Report
Hudson River PCBs Superfund Site

Attachment D – Logistics Model Summary

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A logistics model has been developed for the Hudson River project to simulate the movement of sediment from the dredge areas to the disposal facility. The model allows the simulation of a variety of project conditions and constraints, to identify potential bottlenecks in the material processing systems or sequencing of activities. In addition, the model can help with testing and optimizing systems, procedures, controls, and contingencies for efficient movement of equipment (e.g., barges, rail cars) and dredged material from the river, through the processing facility, and on to the disposal site.

This attachment describes the model, and then provides (for demonstration purposes only) some examples of outputs from the model varying different parameters.

D.1 Model Objectives

The logistics model was designed to simulate the sequence of steps associated with the remedial action at the site, including:

- Inventory dredging;
- Residual dredging;
- Backfilling;
- Capping;
- Barge movement;
- Interaction of barges with recreational boaters;
- Processing including material unloading, processing and storage; and
- Rail car loading and rail operations.

The purpose of the model is to support the overall design of Phase 1 of the project by providing insights into various design scenarios. The model is a tool for evaluation, communication, tracking and forecasting, not for design or establishing the basis of design. As a support tool, the model can evaluate scenarios, such as the effect of adding or removing barges, tugs, locomotives, train sets, and offloading equipment, and it can be used for making minor adjustments to the proposed design. The model can be used as a communications tool providing computer animation to show features such as the movement of barges and recreational traffic on the river, interactions with locks, accumulation of processed material, and rail movement to the disposal site.

The model can also be used as a tracking and forecasting tool. During the early stages of dredging, the model can be compared and validated against the actual operations. Once it has been further validated and verified, the model can be then used to help forecast, identify, and correct problems that may occur during the latter stages of the dredging season (e.g., congestion at locks, trains leaving with partial loads, difficulty meeting dredging completion dates).

The model has a Microsoft® Excel®-based user interface for entering data and collecting output results from different scenarios. The model logic is coded within Arena® version 9.0 discrete event simulation software developed by Rockwell Automation. The user interface facilitates easy entry of input data, execution of the model, and collection of scenario output data even without detailed knowledge of Arena® programming. The data presented in the scenarios used in the model do not represent the basis of final design, nor do the input values represent specifications that will be used for contracting; these are provided for demonstration purposes only. The various contractors on the project will specify the number of dredges, barges, tugs, etc., that are necessary to meet the project's requirements. The model, however, may be used as part of the process of evaluating contractor proposals.

Because some of the input data cannot be known with certainty (e.g., the probabilities of needing to perform one or two passes of residual dredging), the model allows these data to be entered as random variables. Random variables are entered in the form of minimum, most likely, and maximum estimates that define a PERT probability distribution function. Stochastic discrete event simulation, based on probabilistic distributions, is used during the running of the model to analyze the effects of uncertainty.

D.2 Input Data

The model requires a large number and variety of input data. The model uses more than 3,000 random variables and 57 static variables. The user interface is menu driven and the menus represent various categories of data, presented as data "input sheets." The primary menus include the following.

Sediment Removal Definition – This input sheet provides information from the Phase 1 Dredge Schedule that is used to guide the modeling for processes such as inventory and residual dredging and backfilling operations. Inventory and residual dredging are modeled as sediment removal units (SRUs). Each SRU consists of approximately 1,000 cubic yards (cy) of *in situ* sediment, about the amount that would fill one full-size barge. Each SRU represent a sub-division of a Sediment Removal Area (SRA) (examples of SRAs include NTIP01 and EGIA01A). The "Sediment Removal Definition" screen allows the user to define which SRUs make up each SRA. It also provides input to the model regarding the size of barge that can be used at each SRU location.

Backfilling operations are modeled at the Certification Unit (CU) level. Each CU represents an approximate 5-acre subdivision of an SRA. The "Sediment Removal Definition" input sheet provides data that indicate the relationship among the various SRAs, SRUs and CUs. Note that these CUs were developed and used for purposes of the logistics model only; these differ slightly from the CUs defined in the Phase 1 Dredging Operations Drawings.

Dredging Parameters – This input sheet contains information specific to each SRU developed during the Intermediate Design process, including estimates of:

- *In situ* removal quantity (cy);
- Inventory removal rate (*in situ* cy per hour);
- Free water production rate, the amount of water that is entrained with the *in situ* sediment as it is dredged (cy per *in situ* cy);
- *In situ* dry density (tons per *in situ* cy);
- Monitoring delay after inventory dredging (days);
- Re-dredge probability after inventory dredging (%); and
- Re-dredge probability after first pass residual dredging (%).

Dredge Plan – The "Dredge Plan" input sheet provides the model with data regarding the planned sequence for performing inventory and residual dredging in each SRU. While the model honors the sequence provided in these data, it is possible during a given simulation for the model to fall behind or outrun the Phase 1 Dredge

Schedule in terms of the actual day a given SRU is dredged, depending on dredge rates sampled from the input probability distribution function.

Sediment Removal Precedence Relationships – Information on the precedent relationships, as they exist for various SRUs, is also entered into the model. This information is provided to the model to verify that when dredging is complete for all SRUs within a given SRA, the model will direct the dredge to the SRUs within the next appropriate SRA as determined by the Phase 1 Dredge Schedule.

Backfill Parameters – Input data related to the backfilling operations include the volume of material to be placed within each CU, based on the planned area of the CU, and an average backfill depth. A delay time between dredging and backfilling is incorporated, to allow the time needed to confirm that the Residuals Performance Standard had been met within the CU following the completion of inventory and residual dredging.

Processing Parameters – The primary processing parameter information input to the model includes the following:

- Dredged material offload rate (from barge to processing facility);
- Silt / clay fraction associated with the *in situ* sediments in a given SRU;
- Coarse material processing rate through the dewatering facility (tons per hour); and
- Fines processing rate through the dewatering facility (tons per hour).

Miscellaneous Processing Parameters – Other miscellaneous processing parameters are contained within a separate input sheet, to provide data needed by the model to perform process material balance calculations. These parameters include:

- Processed coarse material percent solids by weight;
- Processed fine material percent solids by weight;
- Processed coarse material dry bulk density (tons/cy); and
- Processed fine material dry bulk density (tons/cy).

Rail Yard Parameters – Parameters related to the rail yard and rail operations are also input into the model. These parameters include:

- Number of locomotives;
- Number of trains sets;
- Cars per train set; and
- Travel times between the processing facility and disposal location.

Altering input values such as the number of train sets or locomotives will create scenarios to evaluate the effect on output parameters, such as overall operations completion time and the size of the processing stockpiles (cy of coarse and fine sediments) that will result from the various scenarios.

Travel Distances between SRAs – The travel distances between the various SRAs are also entered into the model. The model requires these data to calculate the amount of time (based on the speed of tugs) for the movement of full and empty barges between the SRAs, Lock 7, and processing facility. These distances are calculated from the center of each SRA. The same distance is used for all SRUs within a given SRA.

Number of Resources – Certain resource variables are also input into the model, including the number of:

- Inventory dredges;
- Residual dredges;
- Dredged material barges;
- Backfill barges; and
- Tugs.

As with the rail parameters, many of these parameters can be altered to evaluate the overall effect on completion times, stock pile sizes, and other model outputs to understand the relationship between productivity and mechanical resources.

Recreational Boaters – Recreational boaters may interact with the dredging operations. In particular, recreational boaters moving north and south through Lock 7 may at times delay the entry of tug and barge traffic to the locks. Therefore, information regarding the number of recreational boaters that could be moving through the locks at any given time period is entered into the model. The recreational boaters input information is placed into the model in the form of minimum, most likely, and maximum estimates for the numbers of recreation boats entering Lock 7 for given time periods as well as the percentage of these boats that enter Lock 7 from the south versus from the north. The estimates provided in this input sheet are based on actual Lock 7 data obtained from New York State Canal Corporation (NYSCC) records for the time period of May 2003 through November 2003.

Seasons – This input sheet provides the following temporal information to the model: the planned time of mobilization for Phase 1 operations; the actual start date for dredging; and the actual start date for rail operations.

Other Miscellaneous Parameters – This input sheet provides information regarding the capacity of barges, the speed of tugs, and Lock 7 rates (open, close, fill, drain, enter, exit). These data, along with the recreational boater data, are used to model movements on the river and interactions at Lock 7. A final input included in this input sheet is the number of replications that the user chooses to run the model. This is for the purpose of probabilistic simulation. The model samples from the probability distribution functions representing all uncertain input parameters at the beginning of each replication. As outputs, the completion dates, stockpile sizes, train trips, tonnage of material disposed, etc. are then reported as the averages along with minimum and maximum values. The data are also available for additional statistical analysis including the calculation of variance, standard deviation, and probability percentiles.

D.3 Model Logic

A generalized description of the model logic is presented below.

Dredging and Backfilling Operations – The model is programmed such that it honors the sequencing associated with the Phase 1 Dredge Schedule, SRU precedence data, and season input information. The volume of material and the dredging rate (cy per hour) contained within the dredging parameters sheet is used to calculate the amount of time for the completion of each SRU.

At the start of dredging operations, empty barges are sent to the SRU location established by the Phase 1 Dredge Schedule. Within the model logic, the volume of sediment that is to be placed in the barge is determined prior to filling the barge. When the barges reach their capacity, the model is coded so that tugs pushing empty barges arrive at the dredging location with empty barges and leave with full barges. The amount of time to fill the barge at a given SRU is a function of the dredging rate (cy per hour) as given by the "Dredging Parameters" input sheet, the size of the barge used at the SRU as given by the "Sediment Removal Definition" input sheet, and the capacity of the given barge as provided within the "Miscellaneous Parameters" input sheet.

The time for a full barge to reach the processing facility is determined by: the distance between the center of the SRA from which the barge is traveling and Lock 7 plus the distance from Lock 7 to the processing facility; and the average speed of the tug. This information is provided within the "Travel Distances Between SRAs" and "Miscellaneous Parameters" input sheets.

As a full barge moves towards Lock 7, the lock may be occupied by either recreational traffic or tugs moving between the processing facility and SRAs. The frequency of recreational boaters moving in either direction through the lock is determined by the data provided by the "Recreational Boaters" input sheet. The frequency of tug arrival at Lock 7 is determined by the productivity rate at given SRU, the number of dredging operations (SRUs) occurring, the distance from the SRA to the lock, and the number of tugs (both for dredging operations and backfill operations) operating at any one time. The frequency is also influenced by the barge offloading rate at the processing facility and the time for the empty barge to move from the processing facility to the lock.

Once dredging is completed at a given SRU, a decision must be made regarding whether or not residual dredging is required at this location. This decision requires collecting and analyzing sediment samples from the SRUs. When laboratory results are obtained, a decision will be made regarding residual dredging. The "Dredging Parameter" input sheet contains data used by the model to account for the time needed to collect and analyze samples and make the decision regarding residual dredging. The model uses an estimated probability to account for the fact that the sample results may indicate that residual dredging is required. The "Dredging Parameters" input sheet also contains the probability that residual dredging is required at a particular SRU. If residual dredging is required, the specified volume will be dredged and the time required for removal of this material is a function of the residual dredge rate. This volume is based on the assumption that the entire area of the SRU will be re-dredged to a depth of 6 inches. Data are also included in the "Dredging Parameters" input sheet to account for the fact that a second pass of residual dredging may be required.

Backfilling operations are performed when inventory and residual dredging is completed within a particular CU and sampling has verified that the CU meets the Residuals Performance Standard. The delay time needed to verify that a given CU can be backfilled is provided within the "Backfill Parameters" input sheet. The total time to complete backfilling operations is based on the estimated amount of fill material needed at each location and the backfill rate.

Precedence of Vessels at Lock 7 – The lock logic for the model is on a first-in/first-out basis (FIFO), although exceptions to this rule are included within the model logic (as described below). These exceptions make use of the term "critical group" of recreational vessels. A critical group is defined as the maximum number of recreational vessels that a tender will lock through at once. The critical group of recreational vessels is an input that can be changed in the user interface. Initially this group is set at a value of four; however, this level can be changed to evaluate various scenarios.

The lock logic is FIFO, unless:

a. The first two vessels in queue are barges and these are followed by recreational vessels. In this case, the first barge will be locked first, followed by the group (less than or equal in size to a critical group) of recreational vessels, then followed by the second barge.
b. If the first vessels in queue are recreational (but less than a critical group) followed by a barge and more recreational vessels, then the lock tender will form a group of up to the critical group of recreational vessels and lock them through before the barge.
c. If a recreational vessel is moving towards the lock in the open position, but is not waiting, and a barge is waiting at the lock at the closed gate, then the lock direction will switch to give priority to the barge.

The following alternative precedence logic is programmed into the model to evaluate the effect of various precedence scenarios:

a. Project vessels having priority over recreational traffic.
b. Recreational vessels having priority over project vessels.
c. Strict FIFO (no exceptions).

Processing Operations – Once a full barge has exited Lock 7, it will proceed to the processing facility for unloading. The time to complete unloading is a function of the offloading rate as provided within the "Processing Parameters" input sheet. This sheet also provides information to the model on the percentage of fine versus coarse material and information on the rate of processing the fine and coarse material. At the processing facility, conversions are made to account for the changing of the material composition based on the processing operation (e.g., separation into coarse-grained and fine-grained streams, dewatering).

Rail Yard Logic – Processed coarse and fine material will be placed in two separate stock piles. Material from these two piles will be loaded on to train sets consisting of 81 cars each. Each car will be loaded with either fine or coarse materials from the fine and coarse piles, with preference given to the piles containing the fine-grained material. Once a train set has been completely loaded it is moved to another location and another set of empty cars is moved into place if available – this is modeled as a delay before the next set can begin loading. Cars are loaded one at a time, and the loaded trains are then transported to the disposal site. The loading rate in tons per hour can be found within the "Rail Parameters" input sheet. Locomotives will arrive as determined by the number of locomotives in the system and the cycle time for a locomotive to proceed from the processing facility to the disposal facility and back again. Once arriving at the processing facility, the locomotive will drop off the empty set of 81 cars it has brought back from the disposal site, and either a fully loaded set of 81 cars will be moved to the disposal site or a partially loaded set will be moved to the disposal site if a fully loaded set is not available. It should be noted that the disposal facility for dredged materials has not yet been selected. However, as described above, the input parameter for the cycle time for movement from the processing facility to the disposal facility and back again can be input once the disposal facility has been selected, taking into account such factors as travel distance and number of hand-offs to different rail carriers along the route to the disposal facility).

D.4 Model Output

The output from the model is represented in several ways. An animated display of the dredging process enables easy visualization of different scenarios and possible bottlenecks during the process. The model also uses tables and graphs to display and summarize various output variables such as completion times, size of stockpiles, train arrival rates, etc. This display enables a clear understanding of different feasible scenarios of the process.

Table D-1, below, presents the types of output data that can be produced for a given set of input variable assumptions. The scenario associated with this output assumes Phase 1 dredging in 2007 and involves using five train sets and three locomotives. This scenario also assumes that the loading of fine material (filter cake) into rail cars takes priority over the loading of coarse material. Since these results are for demonstration purposes only, a detailed listing of all assumptions associated with this scenario is not provided.

Table D-1 –Example Preliminary Results from Model

Draft Preliminary Results
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Summary Assuming 5 Train Sets

Completion Dates

Description	Days	Date
Dredge Completion	191	11/13/2007
Overall Operations	243	1/4/2008
Simulation Start Date		5/7/2007

Processing Piles in Cubic Yards

Item	Average	Min	Maximum
Coarse	40,221	0	70,396
Fine	2,104	0	16,955
Total	42,326	0	75,431

Lock Parameters - Delay in Minutes

Item	Average	Min	Maximum
Barge	84	0	629
Recreational Boaters	55	0	307

Railyard Ouputs

Item	Average	Min	Maximum
Number of partial loads	6	1	11
Number of fulll loads	39	36	41
Number of locomotive trips	44	41	48
Fine Cars	26.68	0	81
Coarse Cars	48.89	0	81
Empty Cars	5.43	0	69
Cars With Material	75.57	12	81
Time Between Locomotive Arrivals (days)	4.76	0	12
Cycle Time of Locomotives (days)	14.45	12	18

Figure D-1, below, is a screen shot of the model animation showing the progression of the dredging operations. On this figure the red circles indicate SRUs that still require inventory dredging. Blue circles indicate that residual dredging is required and yellow circles indicate that the SRU is ready for backfill. The circles will turn green when all work in SRU is completed. The date and progress indicated is for one set of input data and for one replication of the model.

Figure D-1 – Progression of Dredging Operations

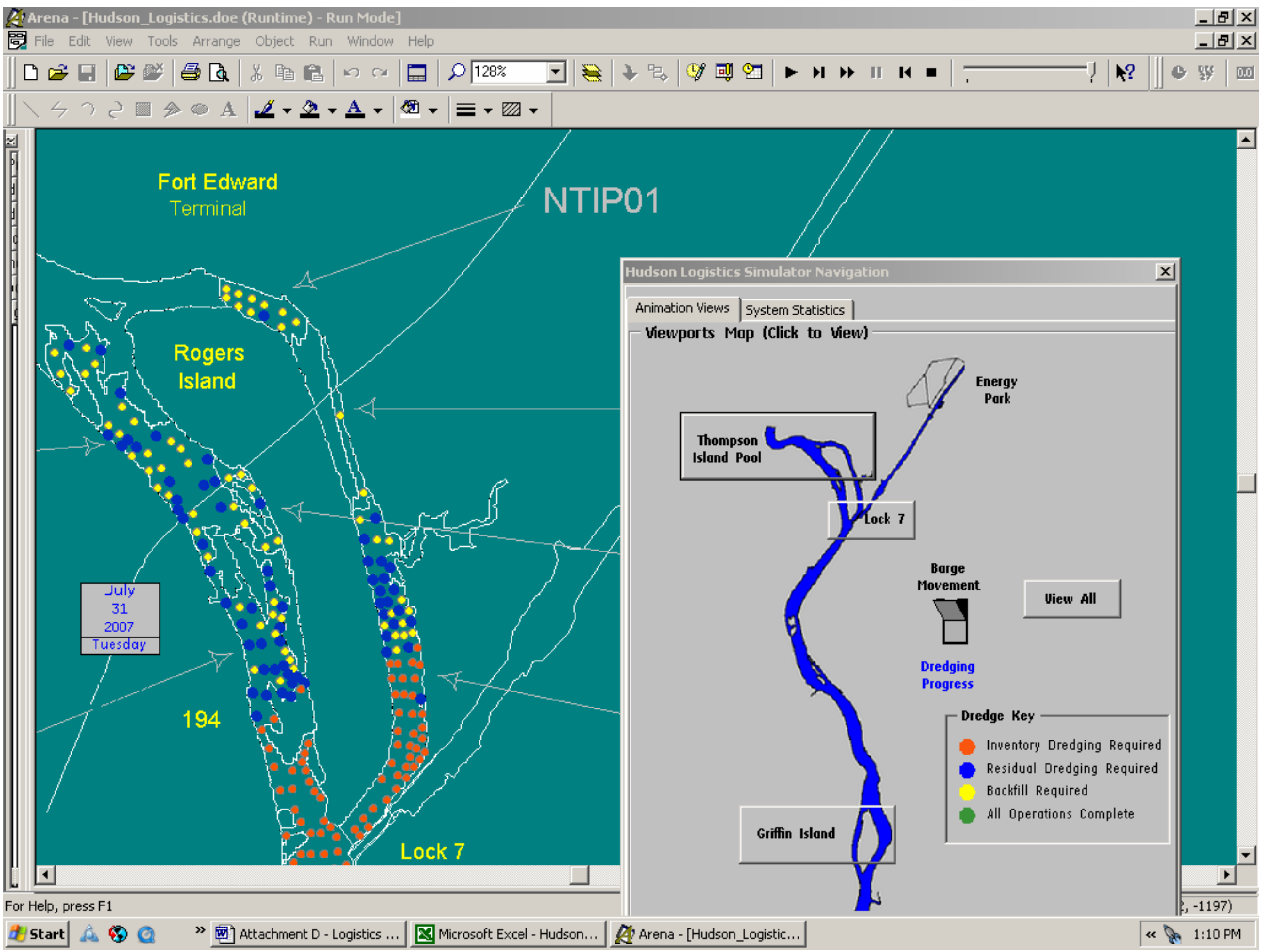
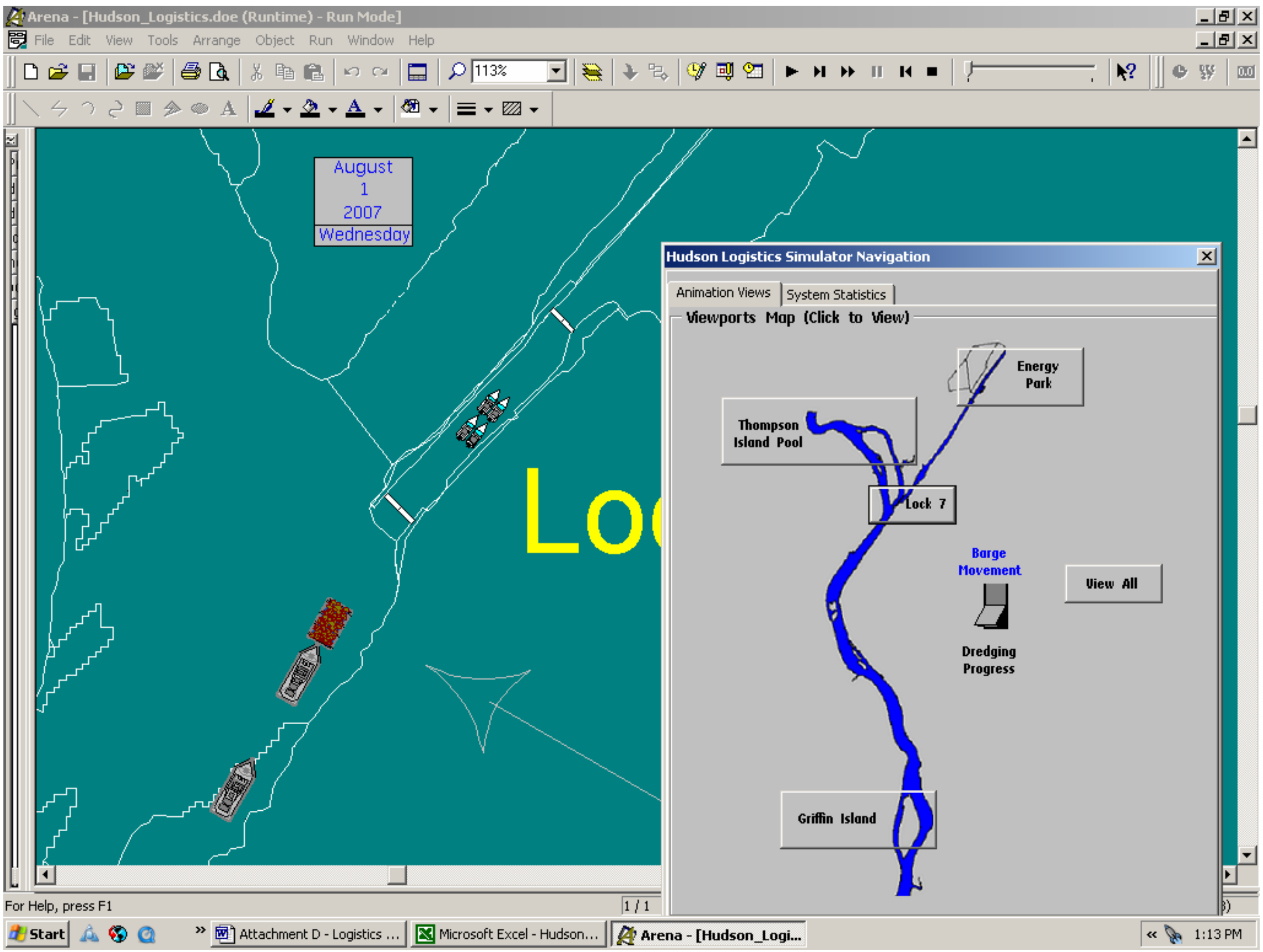


Figure D-2, below, is a screen shot from the model showing barge and recreational boater movement at Lock 7 at a particular point in time. In this simulation, four recreational boaters are in Lock 7 and a tug pushing a full barge load of sediment is waiting to enter the Lock.

Figure D-2 – Barge and Recreational Boater Movement at Lock 7



The outputs can be provided for various input scenarios and can be used to conduct sensitivity analysis on various inputs. For simplicity of presentation, the model results presented below generally give the central tendency of the result and are treated as being deterministic. However, since this is a probabilistic model, each output is actually represented by a probability distribution function. It is important for the model user to understand the uncertainty that the model has quantified in making predictions for various scenarios. This will allow the user to determine if the differing results from two scenarios are statistically significant.

Scenario Results – Effect of Altering the Number of Train Sets and Locomotives – Model results for various scenarios are presented on the following pages. These results include a comparative summary of different scenarios (Table D-2), comparative graphs to illustrate these differences, and graphs illustrating daily processed material stockpile sizes resulting from the use of four, five, and seven train sets for the project. The preliminary indication from these results is the optimum number of train sets may be five. This number of train sets minimizes the number of partial loads leaving the site and has an overall completion date (meaning the last train has left the site) of January 5, 2008. While this is approximately 5 days later than the desired project completion date, scenarios can be evaluated and modified (such as increasing the residual dredging rate) to achieve project completion by December 31, 2007. The size of the stockpile associated with five trains reaches a maximum of 75,000 cy.

Table D-2–Example Comparative Summary from Model

Draft Preliminary Results
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Comparative Summary

Completion Date	**AVERAGE**				
	4-Train	5-Train	6-Train	7-Train	8-Train
Dredge Completion in Days	189	191	194	191	189
Dredge Completion Date	11/12/07	11/14/07	11/17/07	11/14/07	11/12/07
Overall Operations Completion in Days	326	243	214	210	208
Overall Operations Completion Date	03/28/08	01/05/08	12/07/07	12/03/07	12/01/07

Processing Piles in Cubic Yards	**MAXIMUM**				
	4-Train	5-Train	6-Train	7-Train	8-Train
Coarse	103,447	70,396	45,597	35,118	28,787
Fine	16,971	16,955	16,955	16,955	16,955
Total	109,231	75,431	49,054	41,622	40,403

Railyard Ouputs	**AVERAGE**				
	4-Train	5-Train	6-Train	7-Train	8-Train
Number of partial loads	1	6	9	18	30
Number of fulll loads	40	39	38	35	31
Number of locomotive trips	41	44	47	52	61
Fine Cars	29	27	25	23	19
Coarse Cars	52	49	47	42	36
Empty Cars	0	5	9	17	25
Cars With Material	81	76	72	64	56
Wait Time For Full Train Set for Locomotive (Minutes)	8,619	6,168	4,347	3,306	2,535
Time Between Locomotive Arrivals (days)	7	5	4	3	3
Cycle Time of Locomotives (days)	15	14	15	16	16

The graphs below visually represent the data provided in Table D-2, above. A nearly linear increase in the number of partial loads leaving the site as the number of train sets increase is evident. The graphs also indicate that the size of the stockpiles increase as the number of train sets decreases. The graph showing the completion date as a function of train sets indicates that the overall completion date is nearly equivalent using six trains sets or more, but changes considerably when using four or five train sets.

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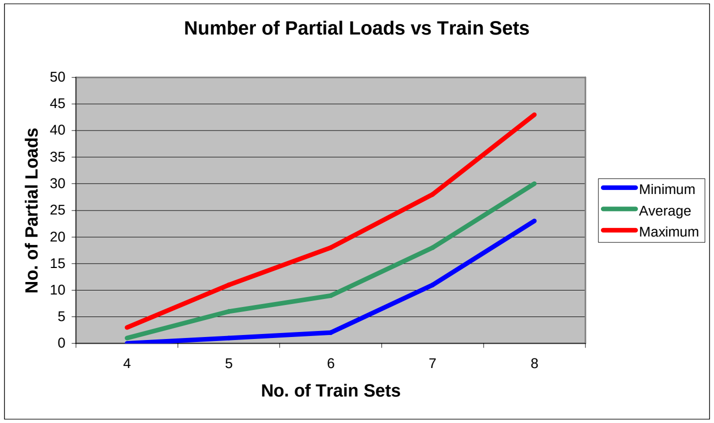
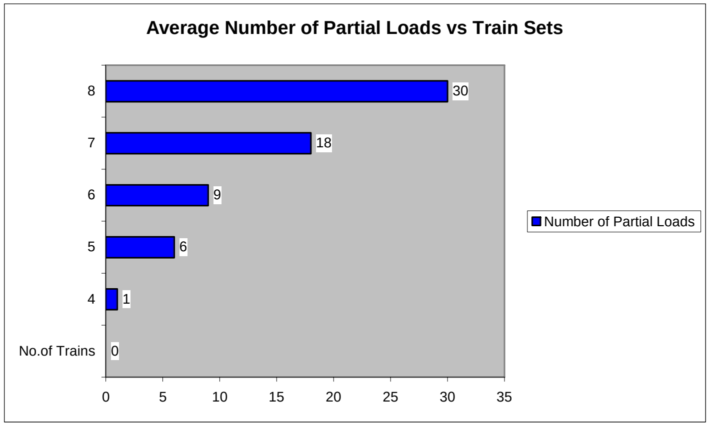
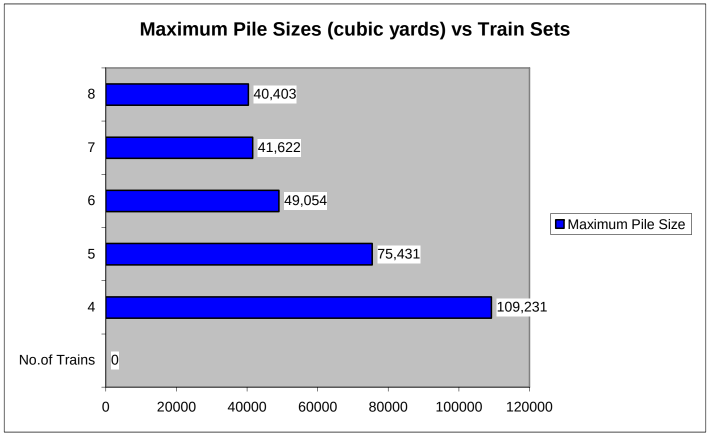
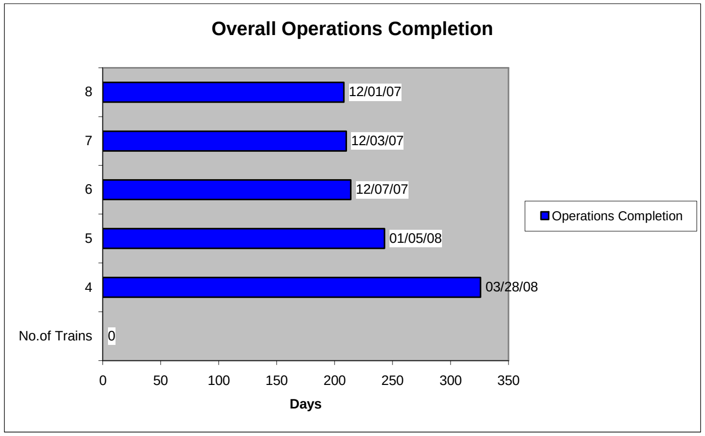
Comparative Graphs









The following graph shows the total size of the coarse and fine stockpiles when using five train sets. Within this graph the volume of fine material is shown directly on top of the volume of coarse material. The total height of the colored areas represents the total volume within the two stockpiles. The fine material is assumed to be preferentially loaded on the trains and therefore its volume does not accumulate as much as the coarse material. Actual rail car loading operations will be established by the contractor and may not follow the patterns shown in this example graph.

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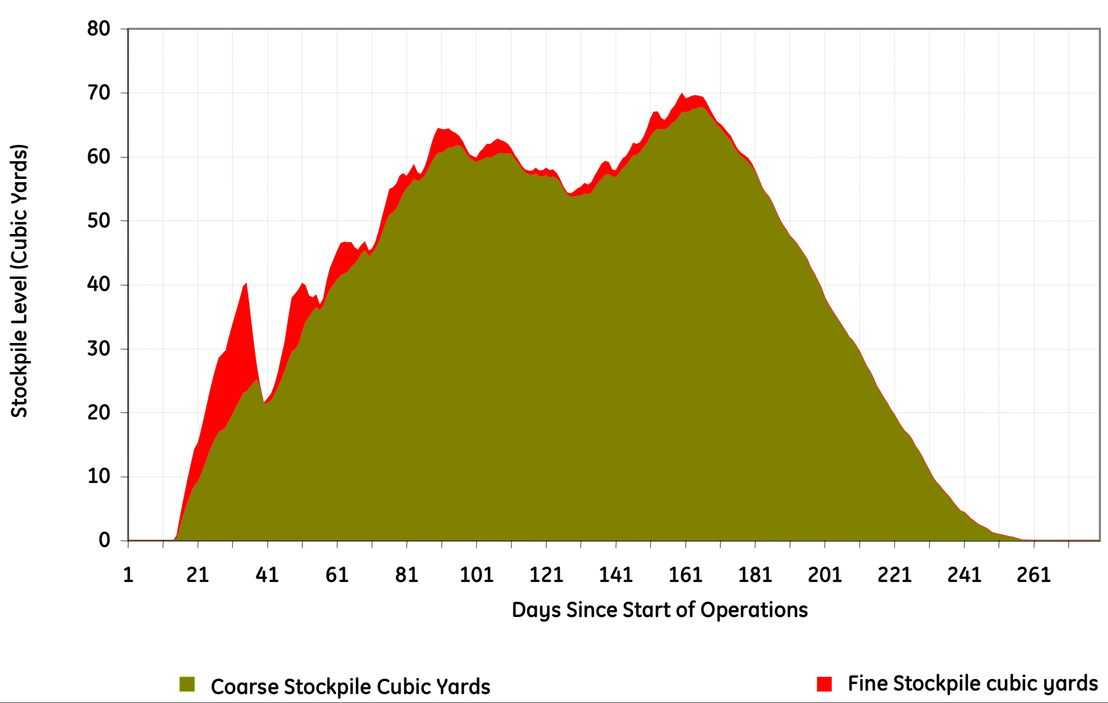
5-Train Set Stockpile Inventory Daily Volume Level



Note: Stockpile quantities are shown in 1,000s of cubic yards.

The following graph shows the size of the processing stockpiles using seven train sets. This graph has more pronounced peaks and valleys than the graph using five trains, because at times, rail transportation is running ahead of processing and loading operations; this situation results in trains leaving with partial loads.

Draft Preliminary Results
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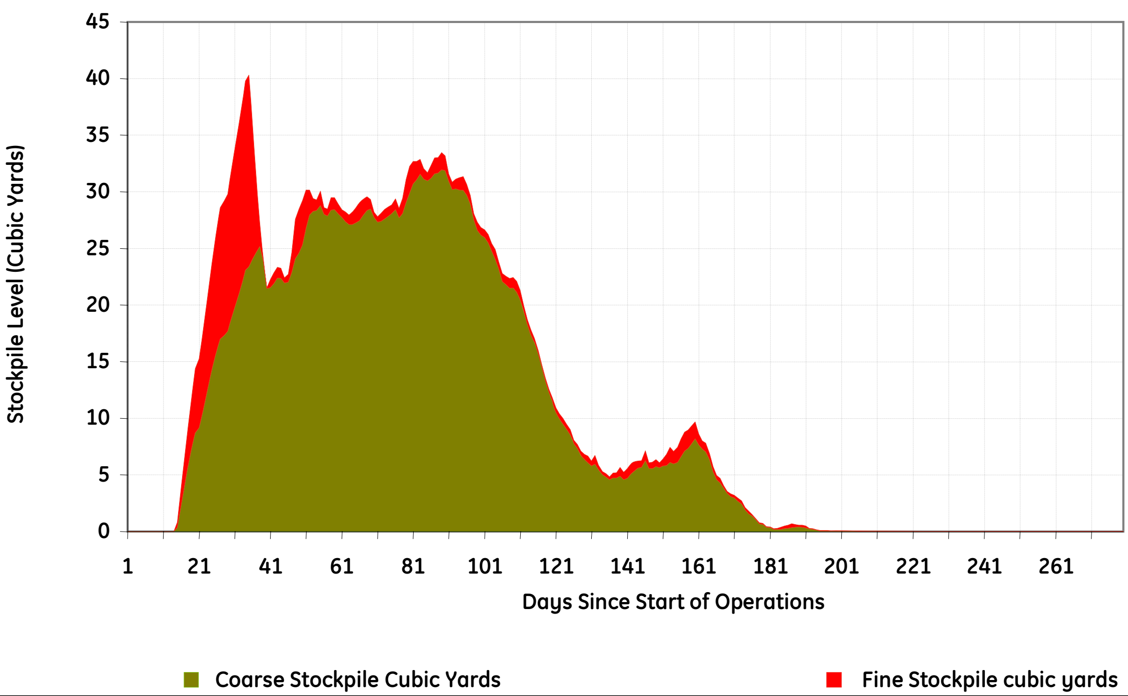
7-Train Set Stockpile Inventory Daily Volume Level



Note: Stockpile quantities are shown in 1,000s of cubic yards.