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HYDRAULIC MODEL STUDY OF SEDIMENTATION AT THE ALLENTOWN WATER SUPPLY INTAKE, LEHIGH RIVER

by

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for

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I. INTRODUCTION

A. Background

This report concerns the physical model study performed to assess sediment deposition potential at the site of the water supply intake in the Lehigh River, under construction for the City of Allentown. A sketch of the intake, designed by O'Brien and Gere, Engineers, is shown in Figures 1 and 2 (taken from Drawing G-3, "Location, Configuration, and Details", 3-15-84, O'Brien and Gere, Engineers). The intake includes two parallel lines of cylindrical screens, 10 feet apart. Each line is 46.5' long from leading to back edge. The screens will be fully immersed in the main river flow, approximately 50' to 70' from the west bank with the bottom of the screens 1.5' off the river bottom. The design includes provisions to protect the screens from debris, such as ice, using submerged piles set upstream and/or around the piles. The plan shows the top of the pile at the same elevation as the top of the intake to accomodate recreational activities on the river.

Because sediment deposition and accumulation have the potential to interfere with the operation of the intake, the designers and City of Allentown personnel requested that a physical model study be undertaken to assess sediment deposition potential at the site. The effect of the placement of the protective piles on sediment deposition potential is an important aspect of the study.

B. Model Design and Construction

1. Model Scale and Layout

The Lehigh River near the site of the intake has a fairly regular geometry. The west bank slopes steeply to the bottom which is fairly horizontal across to Eve's Island. In the downstream or longitudinal direction, the bottom is also fairly flat for several hundred feet upstream and downstream of the site, typical of a backwater reach upstream of a dam. Because there are no geometric features upstream of the intake that cause strong cross currents or local turbulence, the model has simple geometry, requiring a short upstream reach to establish the flow.

The model is undistorted with a scale ratio, L_R, of 1:15. In the 22' long modeling tank (Photo 1), a 330' reach of river is modeled. The tank is 10' wide, allowing 150' of river width from the west bank towards Eve's Island to be modeled. See Figure 1 for the extent of the model. For a prototype depth of 13', the model depth is 10.4 inches.

2. Flow Rate, Velocity, and Reynolds Number

A choice of prototype flow rate(s) to use in the model must be based on an understanding of potential for scour and deposition in a natural river. At low flow rates, sediment remains on the bottom. At high flows, sediment is scoured from the river bottom and banks. During a flood hydrograph, the flow rate in the river increases to a maximum or peak rate and then decreases or recedes to a base flow. It is during the recession period of a flood hydrograph when sediment (put into motion during the flood rise and crest) settles out of the water column onto the river bed.

A prototype river flow rate of 5000 cfs (ft^3/sec) was chosen for modeling. At 5000 cfs, the average velocity in the river cross-section at the intake site is approximately 1.0 ft/sec. This velocity (and corresponding bottom shear stress) is below the critical threshold value to scour or re-suspend most of the sediment sizes of concern. A much higher flow would cause bottom scour, while at a much lower flow, most sediment would already have deposited.

The average flow in the Lehigh River at Allentown is approximately 2300 cfs and the average flood peak (2.33 year return period) is around 23,000 cfs. Thus, 5000 cfs is a flow value that occurs on the recession of very frequent stream rises. Certainly if the intake structure or piles create a scouring action at 5000 cfs, it will keep its immediate surroundings fairly sediment-free on a continuous basis.

For a scale ratio, L_R, of 1:15, the Froude modeling law allows calculation of model velocity and flow rate. The Froude law is:

$$V_m/V_p = L_R^{1/2}$$

where V is velocity and subscripts m and p refer to model and prototype, respectively. For a prototype velocity of 1.0 ft/sec, the model velocity, V_m, is 0.26 ft/sec.

The river Reynolds number, R, in the model must be greater than 500 to insure a turbulent flow. Using V_m = 0.26 ft/sec, depth, D_m, = 8 inches, and kinematic viscosity, ν = 1×10^{-5} ft^2/sec, the river Reynolds number $V_m D_m / \nu$ is 17,000, which is well above the threshold for turbulence.

The Reynolds numbers for the model pile structures or the model intake structures should be of sufficient magnitude for the drag coefficient, C_D, to be fairly independent of the Reynolds number, R. A graph of C_D vs. R (found in any elementary fluid mechanics text) shows that, for cylinders, C_D is fairly constant for R > 1000. Using an approach velocity of 0.26 ft/sec, a model pile diameter of 1", and model intake structure diameter of 2.4", the Reynolds numbers are 2200 and 5200 for the piles and intake, respectively. Because these values exceed 1000, Reynolds number or viscous scale effects should be negligible.

The model flow rate is given by the relationship:

$$Q_m/Q_p = L_R^{5/2}$$

For the 1:15 scale ratio and a prototype flow of 5000 cfs, a total model flow rate is 5.74 cfs. Because the model approximates one-third of the total river width, the flow rate applied to the model is 1.9 cfs.

The river stage corresponding to a flow of 5000 cfs is approximately 251 feet. This value was interpolated from information supplied by O'Brien and Gere, Engineers which indicated a stage of 248' at "normal" or mean discharge and a stage of 254.5' for the 10-year flood.

While the study was underway, the intake site was dredged. It was then decided to set the river bottom at 238.5' rather than 237' indicated on drawing G-3. The model water surface elevation was adjusted accordingly.

The model intake structures were constructed to take in a controlled flow. A model flow of 0.02 cfs (9 gpm) corresponding to a prototype flow of 17.4 cfs (7825 gpm or 11 mgd) was used throughout the study.

3. Construction

The river model was constructed with a pea gravel bed molded to the bottom topography indicated on drawing G-3 (Figure 1). The gravel was topped with a layer of mortar and painted white. The model intake structures were made from 2.4" OD plastic pipe (Photo 2). The piles used were 1" OD pipe.

C. Calibration and Testing

For the flow rate selected, the tail gate was adjusted to achieve the proper water surface elevation. Velocity measurements were taken across the model to assure that the approach flow was fairly uniform. Dye was also used for a visual assessment of the approach flow. The distribution of the approach flow can be adjusted by placing obstructions and guides in the head tank feeding the model.

The testing procedures utilized several approaches, some of which did not reveal much information about the sediment deposition potential around the intake structures. For instance, a velocity probe placed near the intake structure and close to the bottom showed large variations in velocity measured over 15-second averaging periods. This is due to "wafting" in the vicinity of the intake structure; the flow crosses under the structure in one direction, slows, and then crosses in the other direction. When piles were placed upstream or downstream of the velocity probe, the range and variability of velocity measurements did not appear to change very much compared to the case without piles.

Likewise, injection of food coloring dye through small tubes to allow visualization of streamlines and eddies did not help to assess sediment deposition potential with and without piles.

Scattering of potassium permanganate crystals around the intake structures did provide a credible technique of both flow visualization of near bottom flow patterns and assessment of deposition potential. Photo 3 is a sample of the flow pattern at the intake site as shown by potassium permanganate. After distributing the crystals and observing the slow process of the flow marker washing away, it becomes clear that the rate at which the crystals dissolve and the degree of dilution caused by mixing give the best indication of scouring action and sediment deposition potential. Hence, a videotape was prepared and is submitted as part of this report which documents the essential findings.

II. RESULTS AND DISCUSSION

Knowing that obstacles in the path of a flowing stream create vortices, it was originally hoped that the piles, whose primary purpose is to protect the intake from debris, would help scour the intake area. In actuality, the piles do cause a very localized scouring action, but also tend to baffle the flow and cause "shadows" where scouring action is severely diminished. Two video cassettes have been submitted as part of this report; the first is the original tape and the second is a color-enhanced version. By observing the process of the potassium permanganate dissolving and washing out from around the intake structures with and without piles, the following conclusions can be stated.

1. The intake structures alone, without piles, induce cross-flows and turbulence that inhibit sediment deposition in the immediate area of the intakes at the selected flow rate. The first segment of the videocassette shows quite clearly that the potassium permanganate crystals wash out rapidly within one diameter of the intake. The vertical section of pipe

receiving water from each intake segment seems to be the major cause of turbulence. Also, the approaching flow diverges around the leading edge or nose of the upstream segment(s).

2. Piles should not be placed too closely alongside the intakes, certainly not within two diameters. When a line of five piles is placed perpendicular to the flow with two on the left side and three on the right side of the left line of intakes, the flow was "baffled" (segment 2 on the video). Some scour occurs at the base of each pile, but, both upstream and downstream, the intense color of the dye remains. When the piles closest to the intake are removed, the flow is allowed to sweep alongside the intake, clearing the dye rapidly.

3. Upstream piles should not be placed closer than ten feet from the leading edge of the intakes. As shown in the third scene of the videotape, in which four piles are placed in the flow at some distance from the intakes, a pile directly upstream causes the flow to diverge at that point and the current at the nose of the intake is weakened.

III. CONCLUSIONS

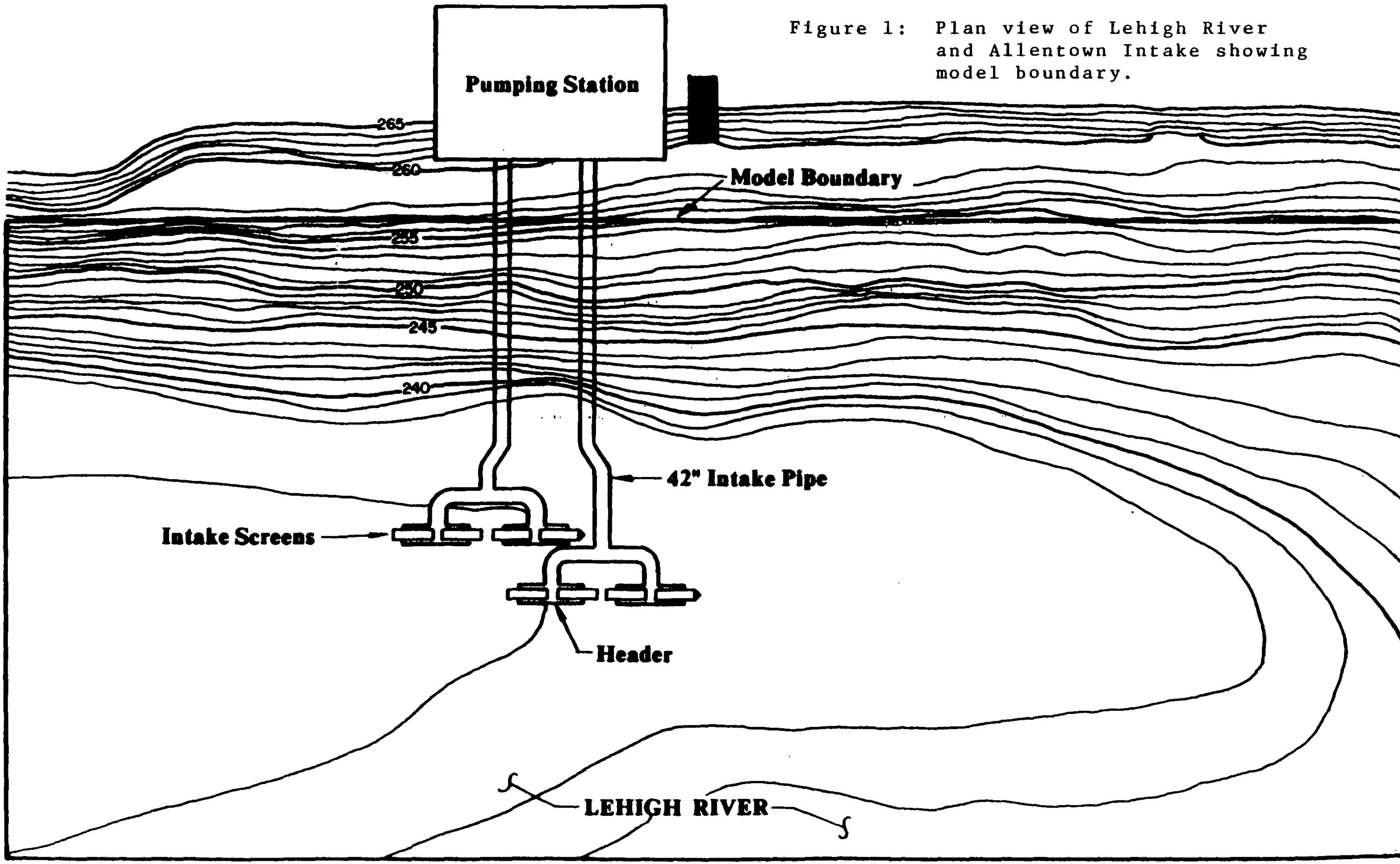
The following conclusions include both the results of the dye study and two design considerations.

1. The intake structures induce flow patterns that inhibit sediment deposition in the immediate area.
2. Piles close to the intake or to one another baffle the flow, creating an environment for sediment deposition.
3. Piles should not be placed closer than 6 feet alongside nor 10 feet upstream of the intakes.
4. Piles with small diameter will cause less baffling of the flow than larger diameter piles, although too small piles may not withstand forces exerted by debris.
5. The placement of piles and the number of piles should be carefully assessed with regard to the type of debris expected and whether the piles will be effective in stopping or diverting the debris around the intakes. One pile placed 10 to 12 feet upstream of each line of intakes (as shown on drawing G-3) will probably suffice.

IV. ACKNOWLEDGEMENT

Messrs. Larry Rubinson and Larry Paul assisted in the planning and construction of the model and offered valuable insights while running the model.

Figure 1: Plan view of Lehigh River and Allentown Intake showing model boundary.



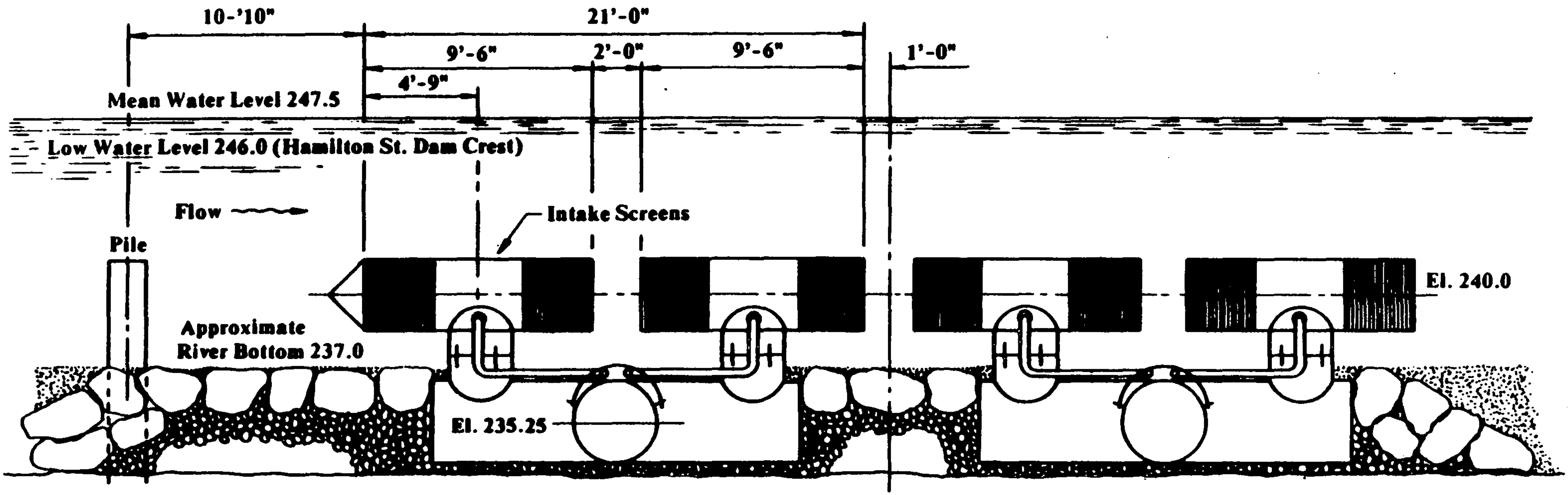
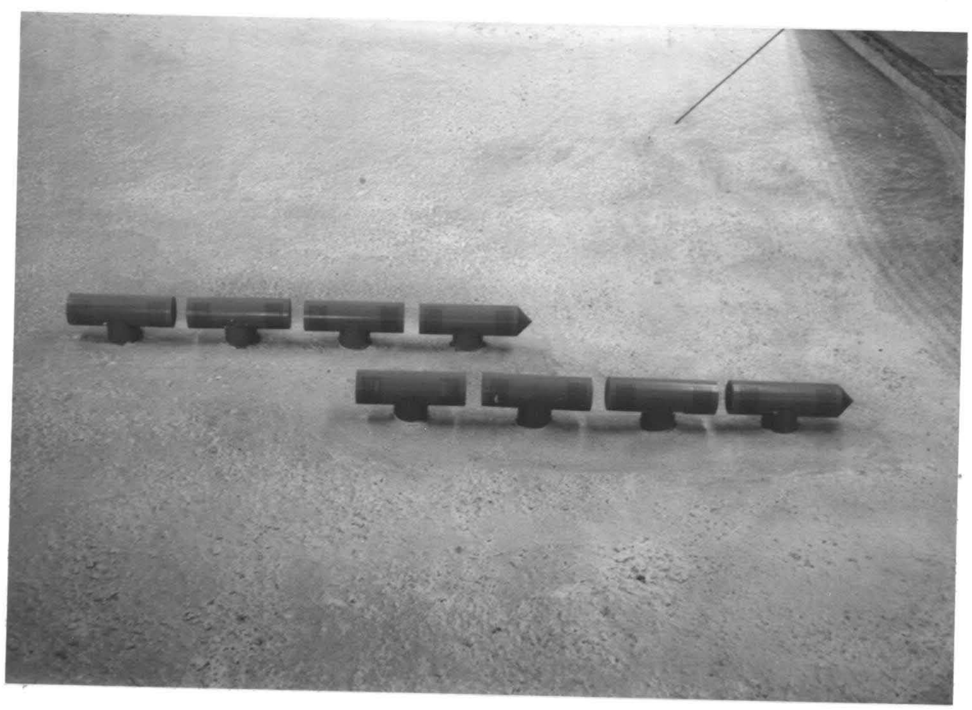


Figure 2: Elevation of one line of intake structures.

Photograph 1: Modeling tank with intakes, looking upstream toward headbox.



Photograph 2: Model intake structures.

Photograph 3: Potassium permanganate crystals in the model with flow from bottom towards top, showing bottom currents.