5 The Funagira stilling basin

The function of a stilling basin downstream of a dam spillway or gates is to dissipate energy from the high-speed flow from the gates, and thereby prevent erosion further downstream of the dam. These structures are generally lined with concrete or riprap, and can include velocity reducing components and dissipating elements like chute blocks, baffle blocks, wing walls and an end sill.

Funagira Dam was built in 1977. The data do not explain the type of stilling basin implemented downstream of Funagira gates. However, the challenges downstream of Funagira dam can be explained as follows:

- The riverbed suffers from erosion possibly due to the partial gate opening and irregular bed level. This leads to formation of eddies which increase erosion.
- The left bank is currently protected using concrete tetra blocks. However, the soil between and under the tetra blocks is eroding, leading to movement of the blocks.

As an example, the bed changes during the flood season of 2015, downstream of the dam, are shown in Figure 5.1 and Figure 5.2. These figures illustrate two bathymetric surveys conducted before and after the flood of 2015. The difference between these maps is shown Figure 5.3.
A study with a physical scale model was conducted by the client to check the problems and how they can be tackled in detail. In the scale model a number of protection options were tested to minimize the erosion, of which an example is shown in Figure 5.4. The bed protection will increase the bed level by around 4 m as shown in Figure 5.5.

In this section, the depth and the length of the stilling basin are checked briefly to recognize the effect of the on-going bed protection work to the capacity of the existing stilling basin to dissipate energy. In the calculation the design discharge of 11,130 m^3s^{-1} shall be considered.

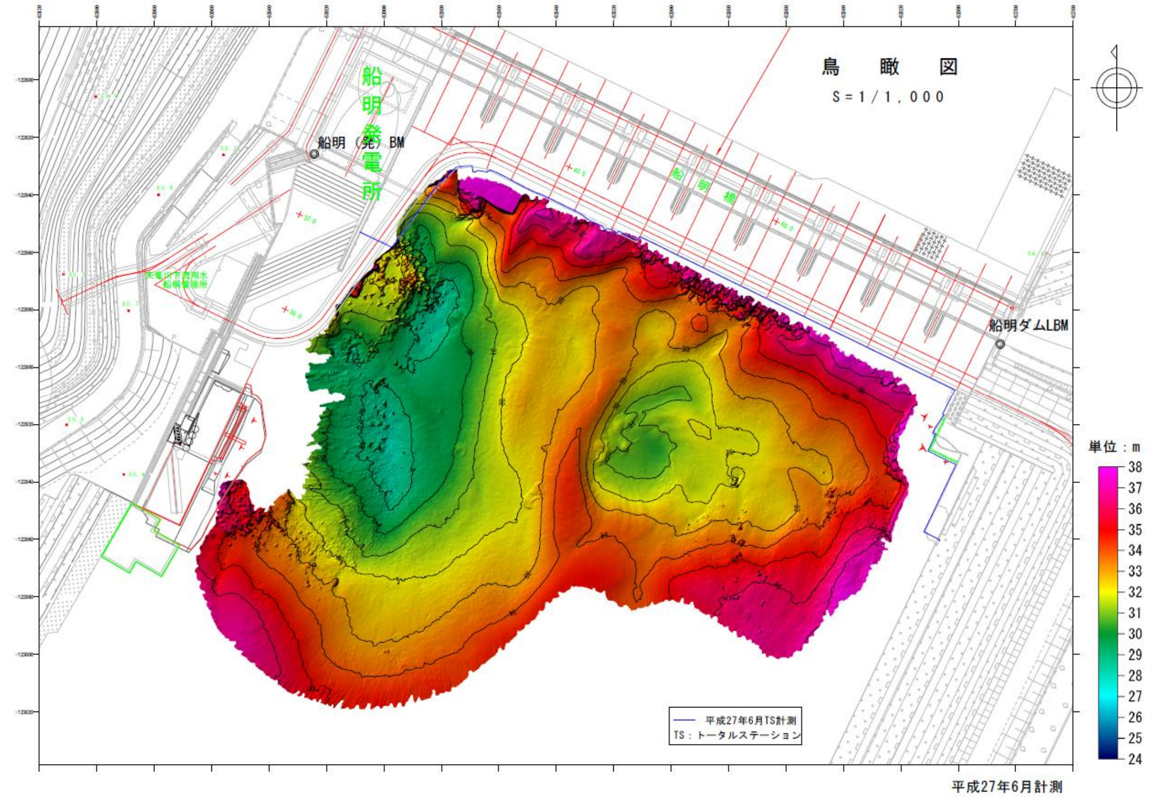


Figure 5.1 Data from the bathymetric survey downstream of Funagira Dam, measured in June 2015 (Before the flood).

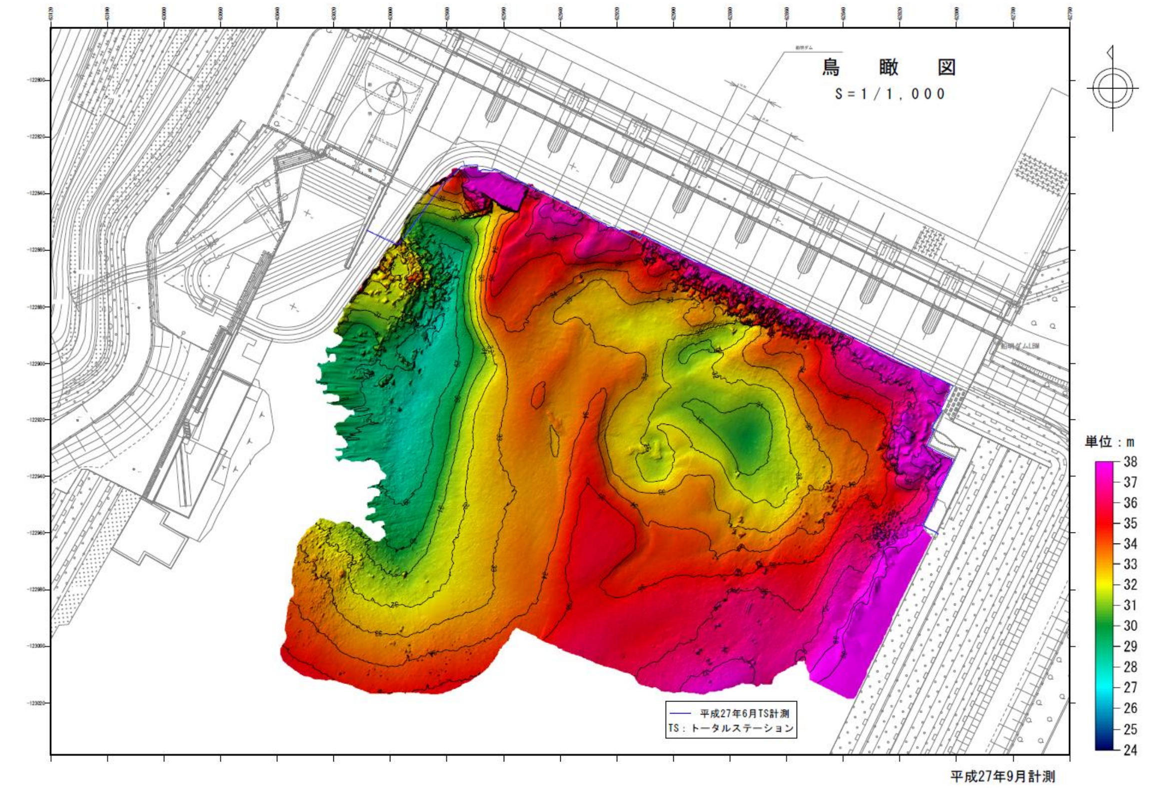


Figure 5.2 The bathymetrical survey downstream of Funagira Dam, measured in September 2015 (After the flood).

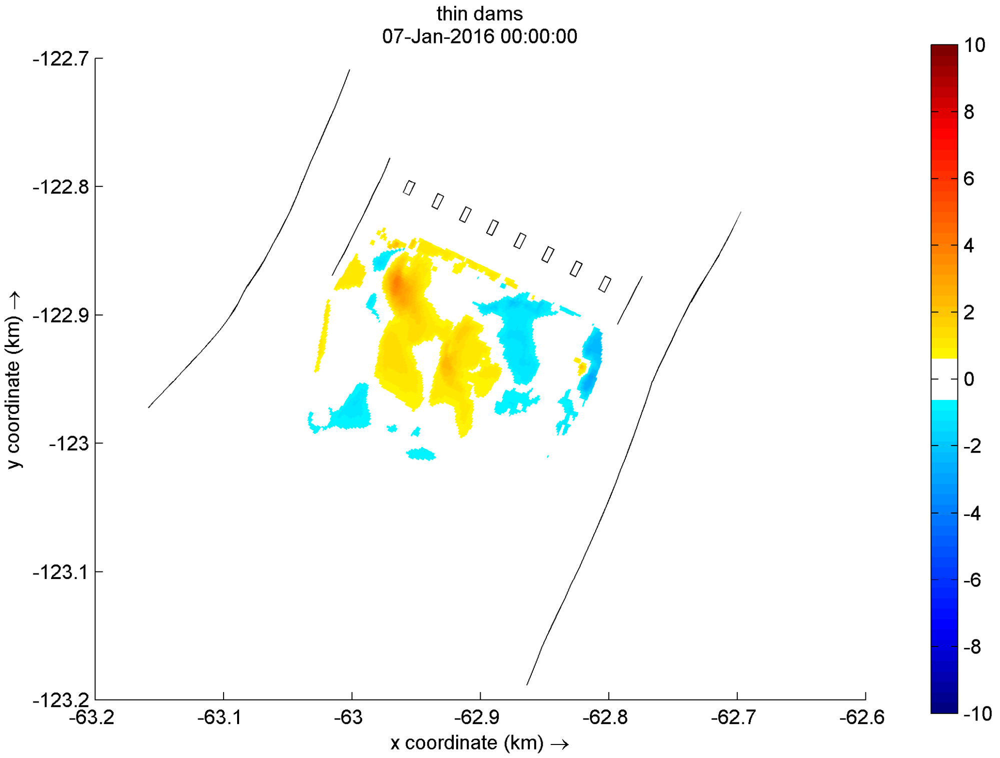


Figure 5.3 The difference between the bathymetric surveys (Sep2015-Jun2015) related to downstream of Funagira Dam

Figure 5.4 The scale model protection prototypes of tetra blocks downstream of Funagira Dam

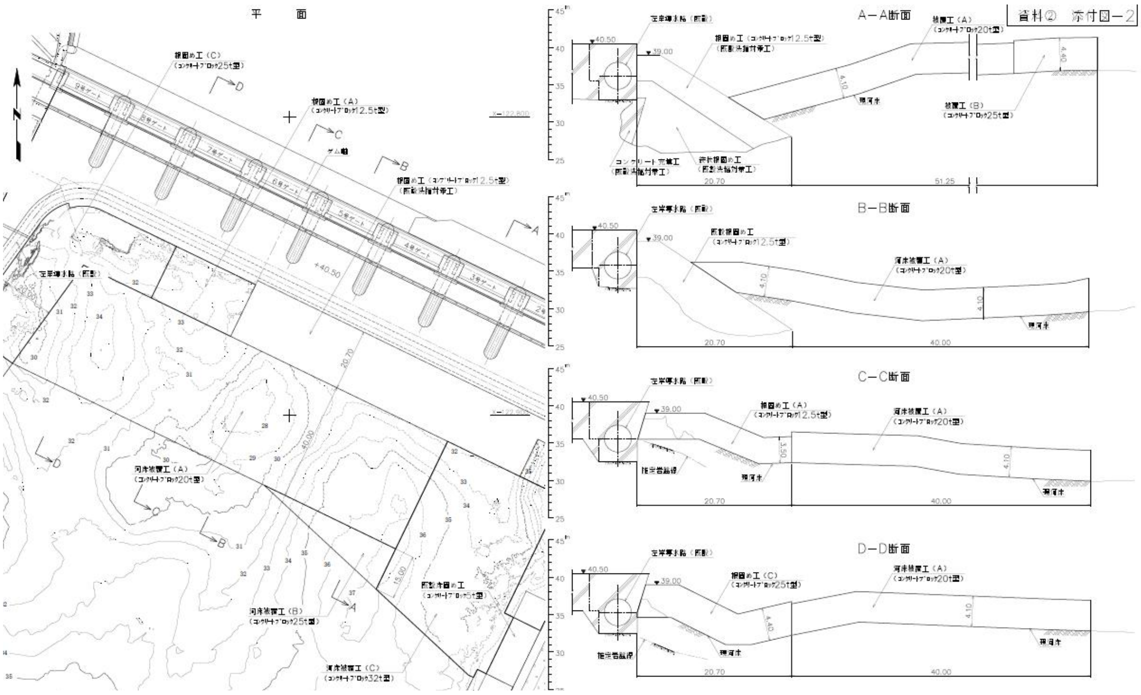


Figure 5.5 The bed protection thickness and dimensions downstream of Funagira Dam

Figure 5.5 shows that the bed protection might not be at the same level in the transverse sections or at any section parallel to the dam. This means that the water depth and the velocity may vary in front of every gate. Basically, placing protection blocks on the bed, without excavation, will raise the bed level of the stilling basin and increase roughness. This may cause higher water levels and as a result the acceleration zone for the hydraulic jump is pushed further downstream. This would require a longer stilling basin.
Using the measured topography of June 2015 and the design discharge (11,130 m^3/s), the expected water depth is estimated by the model as shown in Figure 5.6. The corresponding Froude number of the flow just below the gates (entering the stilling basin) is shown in Figure 5.7. This Froude number is not high meaning that the hydraulic jump may be not too severe. There are other situations (with lower discharges and more suppressed gates) that may have higher impact on the stilling basin. However, the depth of the stilling basin may not vary much.

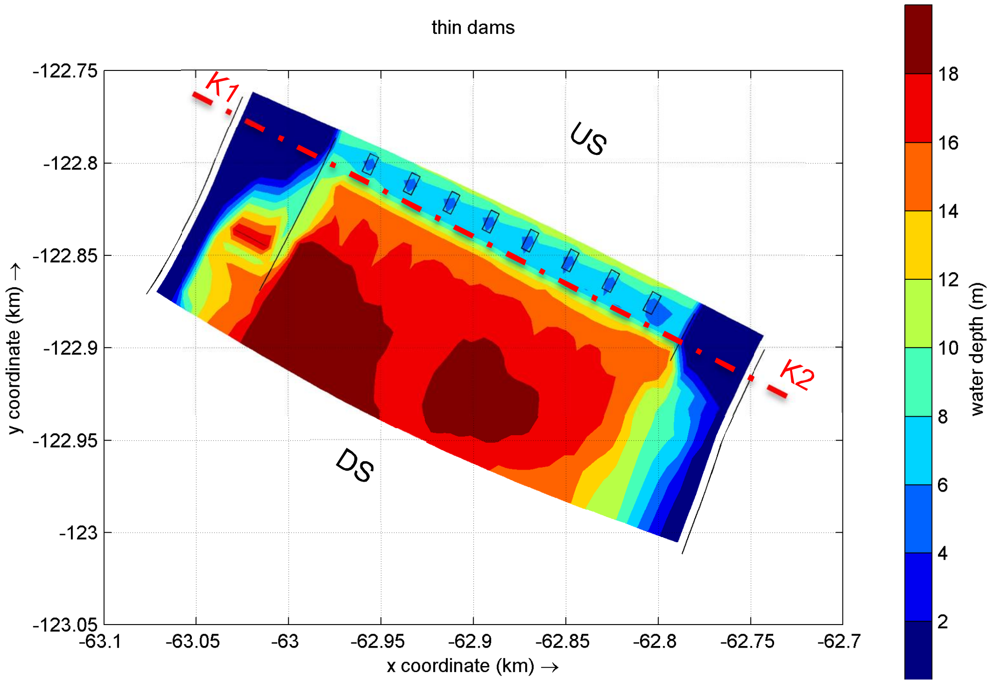


Figure 5.6 The water depth just downstream the dam using the design discharge (11,130 m³/s). The location of section k1-k2 is also illustrated. Flow is directed from top to bottom edge of the figure.

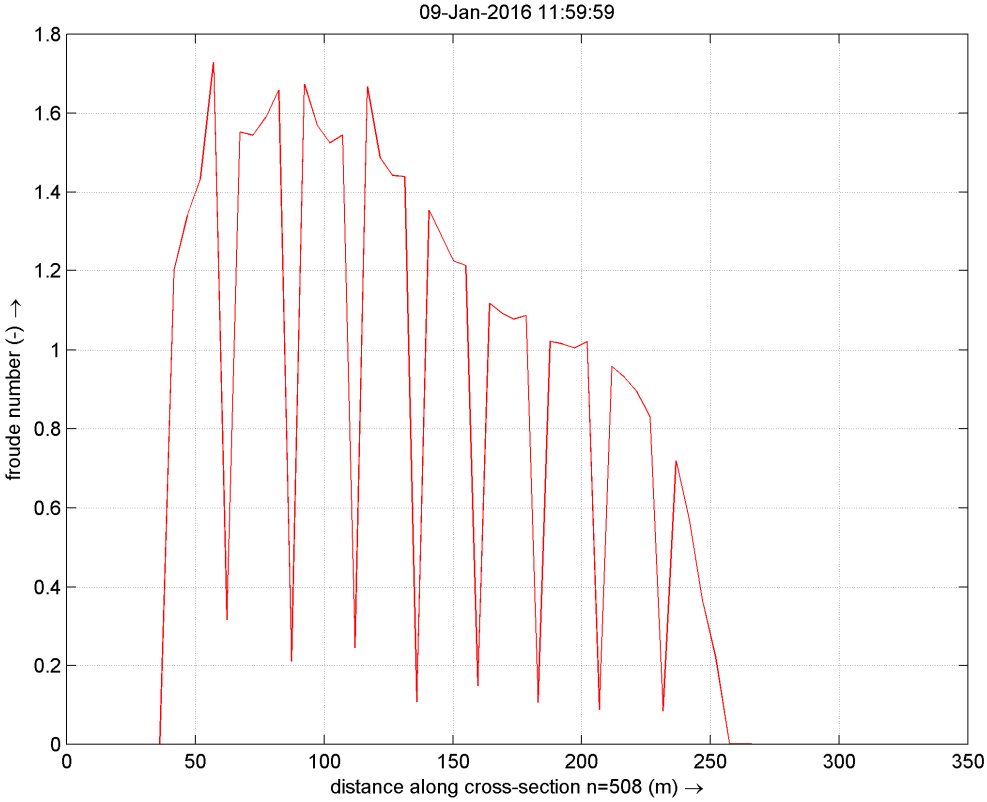


Figure 5.7 The Froude number recorded by the model at k1-k2 section just downstream of the dam (with the area upstream (acceleration zone) of the hydraulic jump). (Looking downstream, the 0 at the right bank)

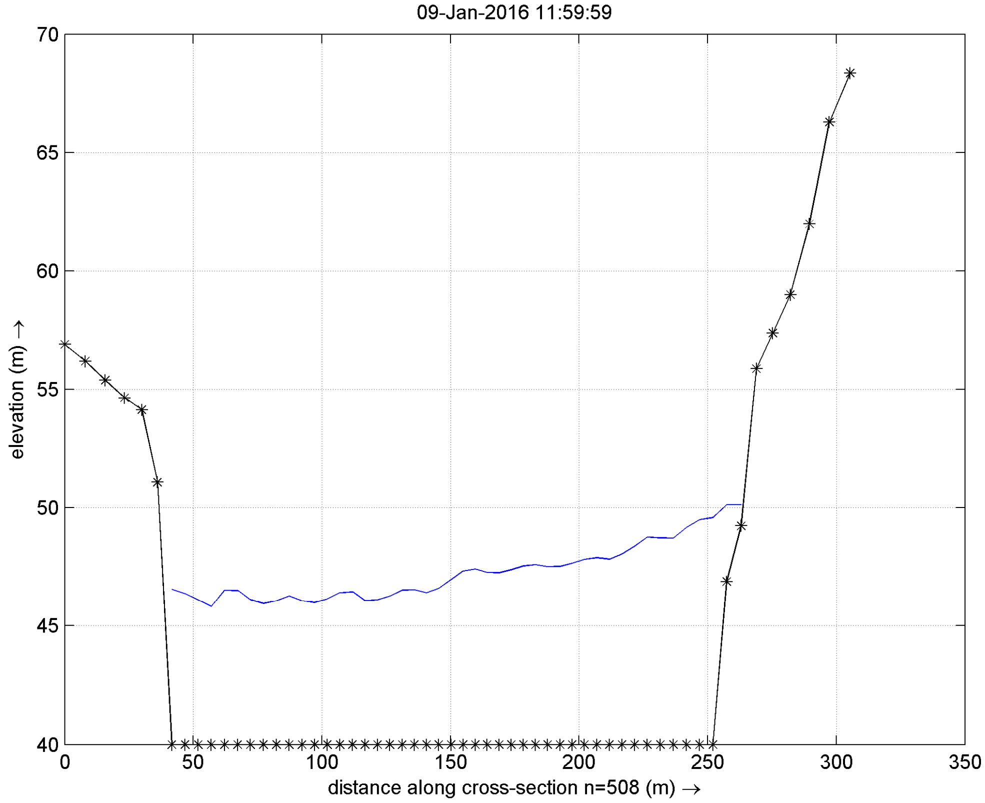
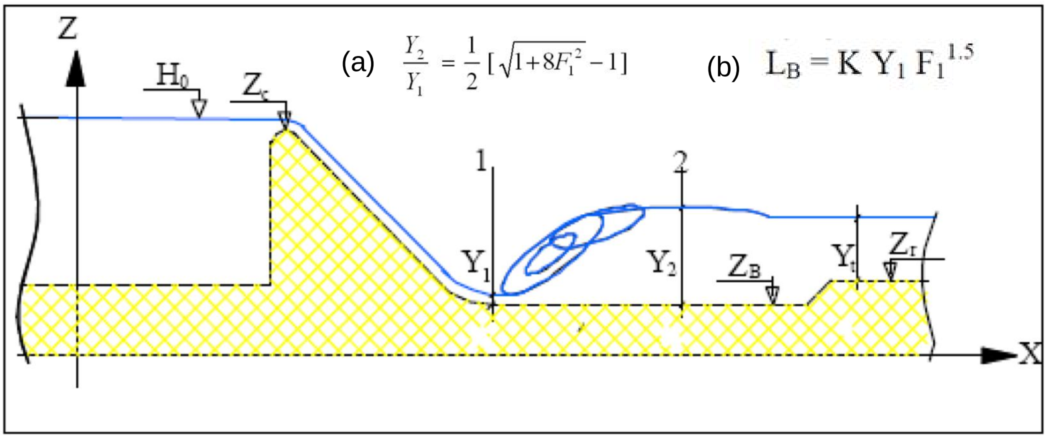


Figure 5.8 The water level and k1-k2 section shape, (Looking D/S, the 0 at the right bank)



Type of Stilling Basin	K
With end sills and 1 or 2 rows of baffle blocks and $F_1 > 4$	1.4
With end sills only	1.7
With end sills and 1 or 2 rows of baffle blocks and $F_1 < 4$	2.0
Flat floor	3.5

Figure 5.9 Schematic diagram of a hydraulic jump in stilling basin (source: Dam Engineering (2) CEI662). Equation (a) is the momentum equation and equation (b) calculates the stilling basin length (L_B). K value is depicted in the table

Rough calculations of expected water depths in the stilling basin are conducted below, using the formula given in Figure 5.9.
We start with a Froude number (Fr) = 1.7 (from Figure 5.7).
Based on that

$$Y_2 = 1.955606\ Y_1$$

At k-k section, the water depth can be around 6.6 m, from Figure 5.8, yielding:

$$Y_2 = 12.907\text{ m} \approx 13\text{ m}$$

The length of the stilling basin can be approximated using equation (b) in Figure 5.9
If k = 3.5 (Figure 5.9), then

$$L_B = 51.2\text{ m} \approx 52\text{ m}$$

From Te Chow (2009), as a conservative approach, L_B also can be approximated as it is almost 6 times Y_2:

$$L_B = 6\,Y_2 \approx 78\text{ m} \approx 80\text{ m}$$

Another approach is developed by US Agriculture Handbook (No. 156)

$$L_B = 4.5\frac{Y_2}{F^{0.38}} \approx 48.\text{ m}$$

The downstream water level of Q11,130 m^3/s is 48 m to 51 m (see Figure 5.10). Based on that, the bed level is expected to be at most 35 m within the first 50~80 m downstream of the dam.
The bed level downstream of the dam based on bathymetric survey of June 2015 is shown in in Figure 5.11. This figure shows that the bed level downstream of gate 1 is higher than 35 m. The higher bed in this area may result in a different behaviour for energy dissipation. Lowering of the bed in this area might be useful to reduce the flow velocity at the left part of the stilling basin area. It is advisable to check this with the scale model.
It is also possible to create a sort of end sill to the stilling basin with a sufficiently high elevation like 41 m, or to create a secondary stilling basin if it is doable. However, the effect of erecting a sill (higher tail water level) may affect the power generation.

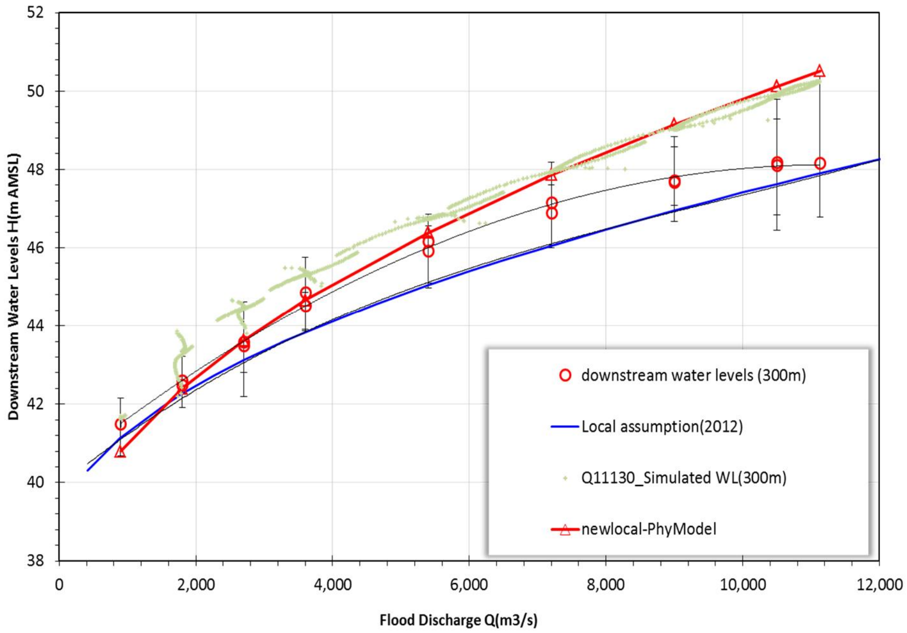


Figure 5.10 The downstream water level observed and calculated 300 m downstream the dam

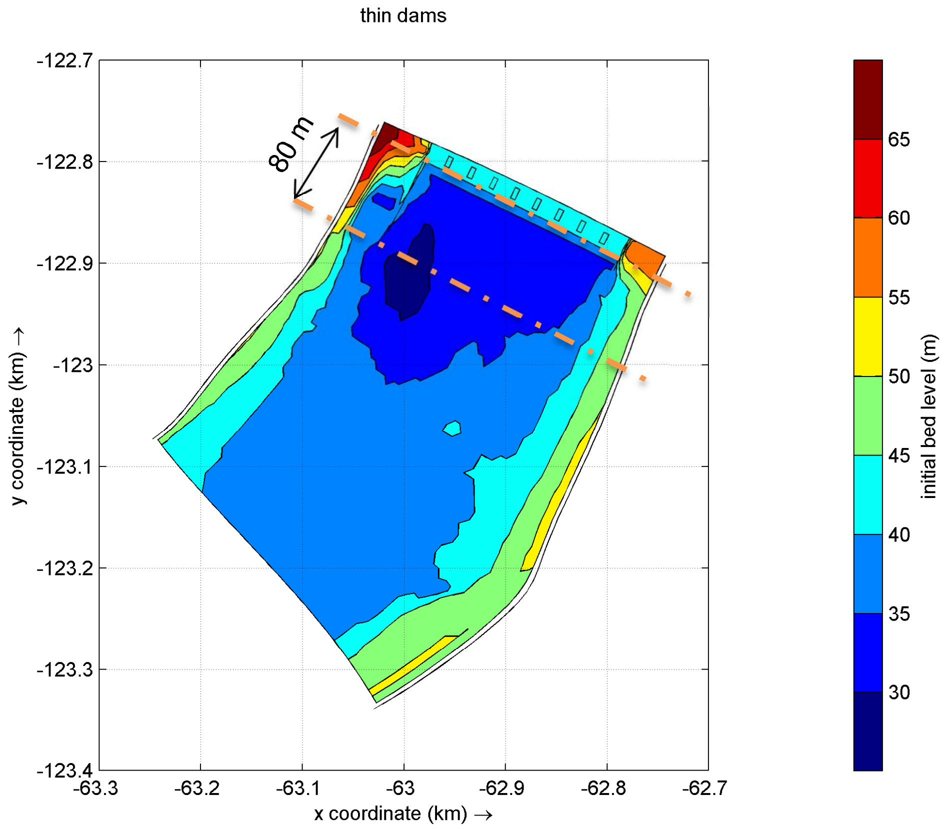


Figure 5.11 The downstream bed level of June 2015 classified in 5 m intervals.

It is useful to keep the bed level after protection around 35 m+MSL. If the protection raises the bed above this level, higher velocities are expected to occur within the downstream area. Figure 5.12 displays the difference in velocity between two scenarios. The difference between those scenarios is the proposed bed protection if it is implemented on the June 2015 topography without excavation.

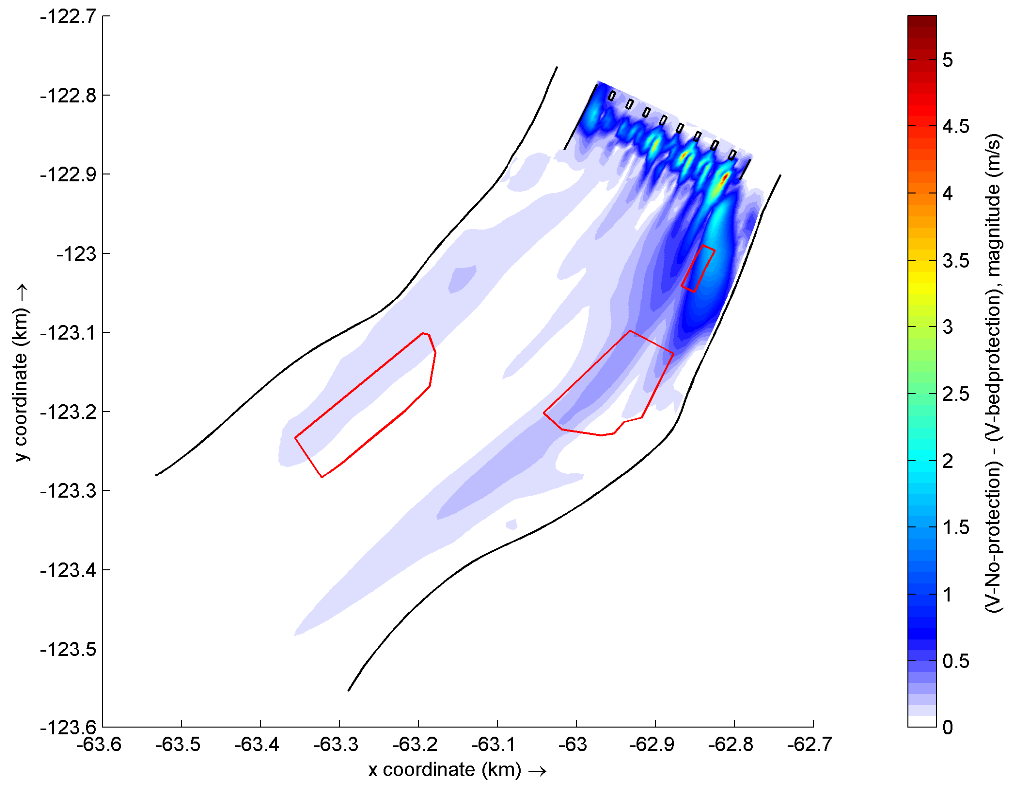


Figure 5.12 The effect of bed protection on the depth average velocity for a discharge of 11130 m³/s passing through the dam.

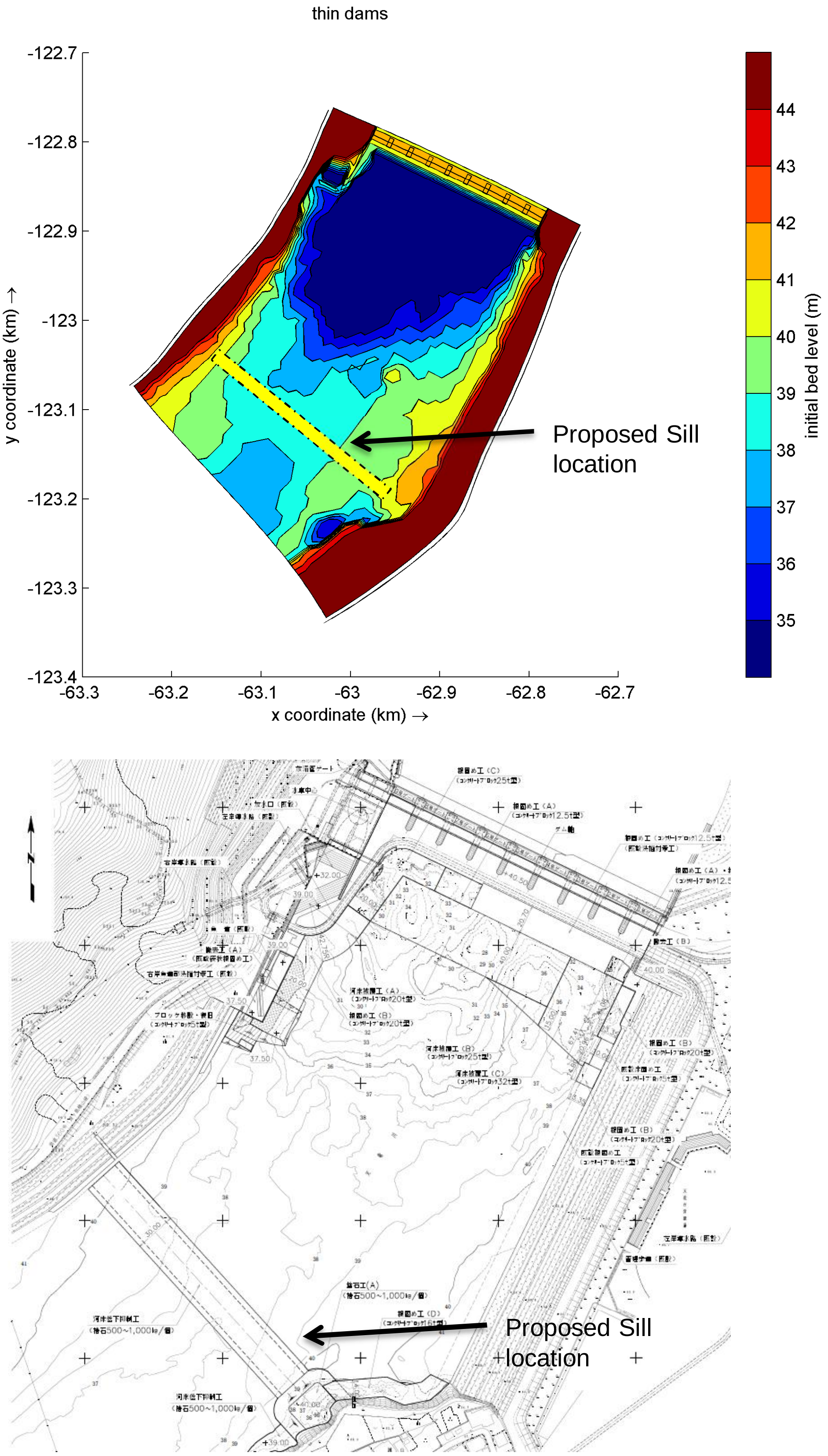


Figure 5.13 Proposed end sill location for the stilling basin of Funagira Dam. The model map and the AutoCAD map show the proposed sill location.