AIRCURRENTS

THE ROLE OF DAMS IN FLOOD RISK REDUCTION: THE HOWARD HANSON DAM AND THE GREEN RIVER VALLEY

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Editor's Note: AIR recently completed a study to model flood risk on the Lower Green River Valley in light of new operational rules on the Howard Hanson Dam. Using the hydraulic model that will be implemented in the AIR U.S. Flood Model currently under development, Dr. Yizhong Qu (AIR Senior Scientist, Hydrology) and Dr. Abebe Jemberie (Research Engineer) assess the potential flood extent and damage to properties.

By Dr. Yizhong Qu and Dr. Abebe Jemberie

A DAM IN DANGER

In January 2009, a heavy rainstorm brought record high inflow to the Eagle Gorge Reservoir in Washington State, southeast of Seattle. Impounding the reservoir is the Howard Hanson Dam, which controls the flow of the Green River to mitigate flooding in the Green River Valley (see figure 2). At the beginning of the storm, the dam was operated in minimum discharge mode; that is, it was set to store as much water as it could accommodate to limit the chance of flooding in downstream communities. Inside the reservoir, the water level quickly rose to 1,189 feet above sea level.

As the water accumulated, a high rate of sediment-laden seepage was observed in the drainage tunnel behind the right abutment. While it is common for a small amount of water to seep through earthen dams, an increased rate of flow or the presence of sediments is usually an indication of erosion caused by frictional forces1. The erosion can cause "piping"—a type of structural weakening that is responsible for a third of earthen dam failures in the United States. To avoid a catastrophic failure, the operator of the dam, the United States Army Corps of Engineers (USACE) Seattle District, took immediate action to lower the reservoir level. Subsequent examination of the structure revealed two depressions in the right abutment (shown in Figure 1), which were believed to be the initial signs of piping.

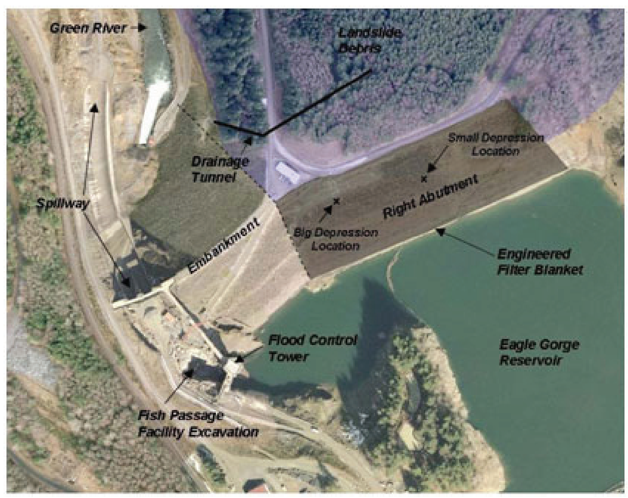

Figure 1. Bird's Eye View of the Howard Hanson Dam Layout (Source: USACE)

Since the storm, with public safety as the primary concern, the USACE has restricted the reservoir's pool level, which is the height of the stored water relative to mean sea level. This reduces the hydraulic loading imposed on the dam, but means that water released to the Lower Green River Valley may exceed the capacity of the downstream levees. As a result, the Hanson Dam will not be able to provide the same level of flood protection that it has during the past 50 years of its existence.

HYDROLOGICAL HISTORY OF THE LOWER GREEN RIVER VALLEY

The Green River flows off the Cascade Mountains, joining the Duwamish River near Seattle. In the past, the Lower Green River Valley—where the towns Auburn, Kent, Renton and Tukwila are located—has flooded violently and frequently, about once every two to three years. The worst flood on record occurred in December 1959, when a flow rate of 28,000 cubic feet per second (cfs) was loaded to the Green River. The entire valley was flooded, and some buildings were flooded up to the second story.

Figure 2. Green River Valley and the Howard Hanson Dam (Source: King County, WA)

Interestingly, the USACE began construction on the Howard Hanson Dam in 1959, although some months before the December flood. Work was completed in 1962. Since then, the dam has played an important role in protecting the valley, and the peak flow rate near Auburn has been capped at around 12,000 cfs. In Figure 3, the annual maximum discharge from 1937 to 2008 is plot against the population of the valley. The drastic reduction in flooding since 1962 has had a marked impact on the local economy, which has grown significantly with the protection offered by the dam.

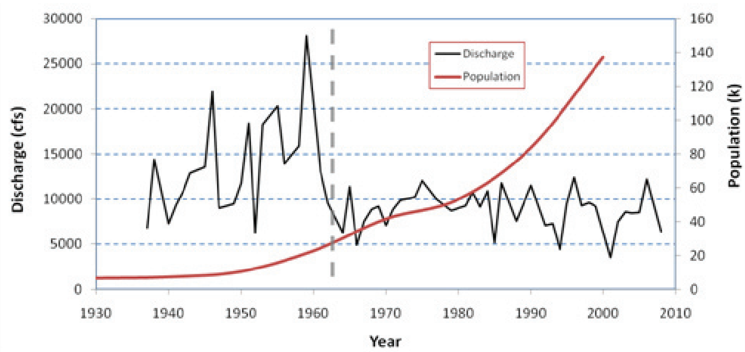

Figure 3. Annual peak discharges at USGS gauge near Auburn and population growth in Lower Green River Valley (Source: AIR)

However, seepage has been a problem in the Hanson Dam since 1965, and one complicating factor is that the right abutment is made of landslide debris accumulated thousands of years ago, instead of engineered fill. In 2002, a nearby earthquake may have weakened the structure. Dye studies in which a dye is released on the reservoir side of the abutment and traced as water seeps through and into the drainage tunnel, have been conducted several times in the past. The most recent, in 2009, indicated the presence of multiple possible flow paths in the abutment. The 2009 incident showed that previous treatments had not completely sealed the flow paths, particularly when the reservoir level is high.

On March 16, 2009, the USACE classified the dam as Dam Safety Action Classification (DSAC) I—Urgent and Compelling—the most severe risk level. In advance of a permanent solution, the USACE has installed grout curtains (rows of closely spaced grout walls injected vertically into the ground under the dam) to seal the abutment. Forty-four million dollars in federal funds have recently been granted to extend the grout curtain along the entire 1000-foot length of the right abutment, which will allow the reservoir to fill to its operational capacity. Other interim projects along the Lower Green River Valley in preparation for the wet season (typically from November through March) include repair and enhancement of levees and local distribution of sandbags. Emergency action plans have been developed by local authorities as well.

However, the hydrological analyses that formed the basis of community planning in the valley were based on the assumption that the dam will be in good service, which is no longer the case. For example, levees along Green River in the valley were built to withstand a dam-regulated discharge occurring with 1% annual exceedance probability, the same flow rate that occurred once every two years, on average, before the dam was built.

MODELING THE INCREASED FLOOD RISK

The USACE has conducted stress-testing simulations in which the discharge near Auburn is estimated for three reservoir inflow events with annual exceedance probabilities of 1%, 2%, and 4% under corresponding operational rules. These simulations produced a range of peak flows near Auburn from which four potential scenarios were chosen by the USACE to generate the flood inundation maps (available online). For instance, under pool level restrictions—under which the dam is currently operating—a 1% annual exceedance event corresponds to a discharge of 25,000 cfs near Auburn, about twice the level the levees were designed for.

Scientists at AIR modeled this scenario with a hydraulic model that will be incorporated in the AIR U.S. Flood Model currently under development. Using high resolution National Elevation Data from the USGS, the model takes into consideration the geometry and roughness of the main river channel to dynamically model its flow under various conditions. AIR then determines the spatial extent of the flood, as well as the flood water depth at each modeled location. The model was calibrated against observations from USGS flow gauges near Auburn.

Although the complete or even partial failure of dams is rare, AIR's probabilistic approach to flood modeling includes such extreme events to ensure that the entire spectrum of potential scenarios involving dams and reservoirs is accurately represented. The trigger mechanisms of dam failure are modeled as well. One common cause of failure is overtopping, when the maximum reservoir capacity cannot accommodate the flood water. This can happen for a variety of reasons, including massive inflow or blockage of the spillway. AIR's modeling approach keeps track of the reservoir volume during simulation. Another important failure mode is seepage/piping or foundation problems. In such cases, the hydraulic loading may not exceed the design level; therefore, failure is modeled probabilistically based on parameters derived from the characteristics of the dam. Figure 4 shows the Lower Green River Valley under normal conditions (left), as well as the AIR-modeled flood extent when the discharge near Auburn reaches 17,000 (center) and 25,000 cfs (right), with the assumption that all lateral flood defenses fail—which is very likely should a discharge of this magnitude occur. The Lower Green River Valley is flat, so once the flood overtops the bank and levees, it will inundate a significant area2. That is why, in terms of spatial coverage, there is only about 10% difference in area when the discharge increases 50% from 17,000 cfs to 25,000 cfs. AIR's results are in line with those published by the USACE.

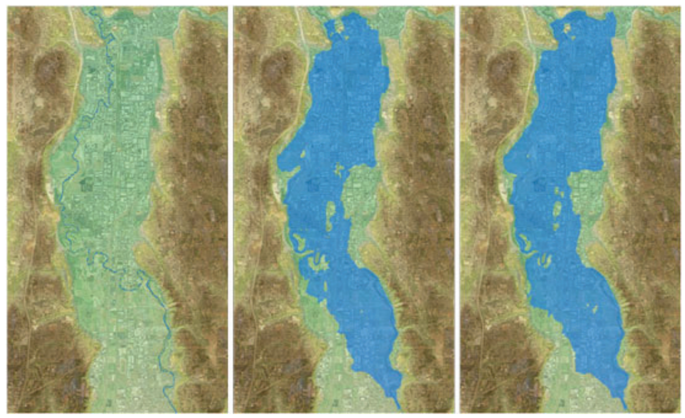

Figure 4. Green River Valley near Auburn: Unflooded (left), and modeled inundation area when the discharge is approximately 17,000 cfs (center) and 25,000 cfs (right), assuming that flood defenses fail (Source: AIR)

EXPOSURES AT RISK

According to AIR's latest U.S. industry exposure database, an estimated USD 30.6 billion of property is located within the valley (see Table 1). Of this, approximately 22.02 and 23.8 billion USD would be affected if the discharge were to reach 17,000 and 25,000 cfs, respectively. Within the valley, nearly 90% of exposures are non-residential, including commercial, industrial and transportation. Furthermore, a higher percentage of commercial and industrial properties are affected for the same discharge compared with residential because they are located closer to the river. Indeed more than 80% of commercial and industrial exposures are located in the flood extent when the discharge is 25,000 cfs, while less than 60% of residential exposures would be affected.

Table 1. Exposure value affected in the valley (Source: AIR)

	Exposure Value (Millions USD)		
Occupancy	Lower Green River Valley	Inside Flood Extent Q = 17,000 cfs	Inside Flood Extent Q = 25,000 cfs
Commercial	16,798	12,245	13,667
Industrial	7839	6,549	6,644
Residential	3486	1,743	1937
Transportation	1124	754	797
Other	1336	730	792
Total	30,583	22,021	23,837

CONCLUDING REMARKS

While the extension of the grout curtain is a suitable interim fix to the Hanson Dam, the permanent solution of a complete concrete cut-off wall, agreed upon by both USACE and an external panel3, will not be finished until 2014 or 2015. Under the current pool restriction rule and with a structurally weakened dam, significant downstream flooding remains a worrisome possibility during this period. With 30 billion USD of exposure at risk, the continued economic viability of these towns is inextricably linked with preventing the catastrophic floods that plagued the Lower Green River Valley prior to the construction of the Howard Hanson Dam in 1962.

It is a race against time; while we cannot predict when the next severe storm will happen, its occurrence is inevitable. With the Hanson Dam operating at less than capacity, the flood risk is clearly heightened and the dam cannot protect against the 1 in 100 year event for which it was designed. However, with significant scientific and computing advances in our ability to reliably model this complex risk, it is apparent what is at stake; we no longer have to wait and see.

The storm in January 2009 served as an important reminder to residents and business owners that they are in fact living on a floodplain. Fortunately, there were no flood-causing events during last year's wet season. Now, as the 2010–2011 storm season approaches, hydrologists, engineers and civil authorities can assess future flood risk and implement long-term solutions and strategies to protect the valley.

REFERENCES

1 QU, YIZHONG. "MODELING GREAT BRITAIN'S FLOOD DEFENSES." AIR CURRENTS. JANUARY 16, 2009. HTTP://WWW.AIR-WORLDWIDE.COM/PUBLICATIONSITEM.ASPX?ID=16230.

2 IT IS WORTH MENTIONING THAT THE LOCAL AUTHORITIES WORK CLOSELY WITH THE USACE TO MITIGATE THE ADVERSE FLOOD RISK. BASED ON THE PREVIOUS HYDROLOGICAL STUDIES BY VARIOUS SOURCES, KING COUNTY AND AFFECTED TOWN AUTHORITIES DEVELOPED EMERGENCY ACTION PLANS AND DEPLOYED REGIONAL AND LOCAL FLOOD MITIGATION MEASURES, WHICH SIGNIFICANTLY IMPROVE THE PROTECTION TO THE LOCAL COMMUNITY. THIS INFORMATION IS CHANGING OVER TIME AND THE DETAILS WERE NOT AVAILABLE FOR THIS STUDY, THEREFORE THEY WERE NOT CONSIDERED IN THIS STUDY.

3 BATTELLE. HOWARD A. HANSON DAM INDEPENDENT EXTERNAL PEER REVIEW FINAL REPORT, DAM SAFETY ACTION CLASSIFICATION GROUP I: ENGINEERING RISK AND RELIABILITY ANALYSIS. PITTSBURGH: U.S. ARMY CORPS OF ENGINEERS, 2010.

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