Condition Assessment Manual

Appendix 1.04 – Guide for Flumes & Open Channels Condition Assessment

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1.0 General

Free-flow water conveyances such as flumes and open channels are an important component in the power generation process at a hydropower facility. Free-flow water conveyances operate under the laws of open channel flow and are primarily used to divert flow from the upstream reservoir or forebay to the dam intake. Since flumes and open channels are periodically exposed to severe service conditions such as turbulent water and severe weather, they are likely to experience several maintenance and reliability issues. These issues can include:

- Erosion
- Structural deterioration (concrete spalling, steel corrosion, cracking, etc.)
- Aquatic growth
- Sedimentation
- Seepage
- Ice and debris build-up
- Lining deterioration
- Instability of adjacent slopes

Emergency repairs, unscheduled maintenance, or replacement of flume and open channel parts can be very costly. Therefore, routine maintenance and condition assessments are important in extending the life expectancy of conveyance parts, limiting unscheduled shutdowns, and improving hydraulic performance by minimizing seepage and head losses. By performing a condition assessment, plants can estimate the remaining life expectancy, identify potential failure risks, and evaluate the benefits of upgrades.

For flumes and open channels, the three following steps are necessary to establish a condition indicator:

1) What parts are to be included in the condition assessment and what is their level of importance (parts and their weighting factors)?

2) What metrics/parameters are to be investigated for the quantitative condition assessment and what is their level of importance (condition parameters and their weighting factors)?

3) How to assign numerical scores to the parts (rating criteria)?

This Appendix provides guides to help answer the questions above, which can be applied to flumes and open channels. Flumes and open channels can serve varied roles in a hydropower facility such as intake canals and tailrace channels. There are also variations in conveyance general arrangements, construction materials, and accessibility for maintenance. Therefore, separate water conveyances at a single facility may have different Operating and Maintenance (O&M) histories and will have different rating criteria. This condition assessment is to be performed on a single water conveyance. For example, separate assessments will be performed on intake canals and tailrace channels. Since plants can have a large variation in the arrangement of water conveyances, the guides provided in this Appendix cannot quantify all factors which can affect individual conveyance conditions. Mitigating factors not included in this Guide may trigger testing and further evaluation to determine the final score of the water conveyance condition and aid in the decision of part replacement or rehabilitation.

This Appendix is not intended to define flume and open channel maintenance practices or describe in detail inspections, tests, or measurements. Utility-specific maintenance policies and procedures must be consulted for such information.

2.0 Constituent Parts Analysis

For flumes and open channels, the constituent parts are analyzed and listed in Table 1 (references to HAP Taxonomy).

If any part (e.g., de-silting chamber) does not exist in a particular conveyance system, this part will be excluded from scoring mechanism by inputting "NA" into the Table. The effect of one part exclusion is usually insignificant to the entire system assessment and does not justify an adjustment of the weighting factors for the other parts.

3.0 Metrics for Condition Assessment

As listed in Table 1, the following five condition parameters are considered for the condition assessment of flumes and open channels:

- The Physical Condition
- The Age
- The Installed Technology Level
- The Operating Restrictions
- The Maintenance Requirement

These five condition parameters are scored based on previous testing and measurements, historical Operation and Maintenance (O&M) records, original design drawings, previous rehabilitation feasibility study reports if available, interviews with plant personnel, and inspections when accessible.

It can be noted that there is a certain level of relevance between the age and physical condition, maintenance needs, or some operating restrictions. However, as a benchmark condition assessment (without specific testing and measurements conducted on site) the five parameters are regarded as providing the basis for assessing the condition of flumes and open channels.

In addition, the Data Quality Indicator, as an independent metrics, is to reflect the quality of the available information and the confidence of the information used for the condition assessment. In some cases, data may be missing, out-of-date, or of questionable integrity. Any of these situations could affect the results of the condition assessment. The scores of data quality are determined by the on-site evaluators for each assessed part to indicate the data availability, integrity, and accuracy; and the confidence of the given condition ratings (MWH 2010).

4.0 Weighting Factors

There are two categories of weighting factors in Table 1. It is recognized that some condition parameters affect the condition to a greater degree than others. The weighting factors for different condition parameters should be pre-determined by consensus among experienced hydraulic and hydropower engineers. Also, some parts are more or less important than other parts to the entire conveyance system, particularly due to the overall facility layout and length of open channels/flumes varying from plant to plant. The weighting factors for constituent parts are hard to be pre-determined; the values filled in Table 1 and in workbook are an example only; they should be adjusted accordingly during the demonstrations and baseline assessments by HAP core process development team with consensus among experienced hydraulic and hydropower engineers. . Then, the weighting factors can be used for the plants with similar open channel/flume arrangement. The range of absolute values of weighting factors will not affect the Condition Indicator of a conveyance system, which is the weighted summation of all scores assigned to the parts and five condition parameters.

Table 1: Typical Flumes/Open Channels Condition Assessment & Scoring

Flumes / Open Channels	Taxonomy ID	Physical Condition Score	Age Score	Installed Technology Score	Operating Restrictions Score	Maintenance Requirement Score	Data Quality Score	Weighting Factors for Parts
Flumes	3.7.1							5.0
Open Channels	3.7.2							5.0
Forebay Structure	3.7.3							5.0
Desilting Chamber	3.7.4							2.0
Weighting Factors for Condition Parameters		2.0	1.0	1.0	1.0	1.5	Data Quality -->	0.00
							Condition Indicator -->	0.00

5.0 Rating Criteria

Physical Condition - Rating Criteria for Flumes/Open Channels

Physical Condition of flume and open channel parts refers to those features that are observable or detected through measurement and testing. It includes lining deterioration, channel blockage (due to debris, ice, eroded materials, etc.), structural deterioration, seepage, foundation/slope instabilities, hydraulic conditions etc. The surface or liner of channels is important since increased surface roughness can affect efficiency by increasing head losses. Excessive seepage can lead to uncontrolled water losses which can also affect efficiency. In addition to efficiency related issues, evidence of adjacent or supporting slope instabilities, severe structural deterioration, severe vibrations, and flow blockage may be an indication of impending failure or safety issues. Therefore, flumes and open channels should be carefully evaluated. The Best Practices for Flumes & Open Channels can assist in evaluating the physical condition. For HAP site assessment, it is important to interview and discuss with plant personnel to help score the physical condition. The results of all related information are analyzed and applied to Chart 1.

Chart 1 Flumes/Open Channels Physical Condition Rating Criteria		
Physical Condition Rating Scale		Physical Condition Score
Excellent	Limited deterioration or damage to liners of water conveyances; no evidence of foundation settlement or deterioration; minimal leakage at joints; no evidence of erosion or instabilities of embankments or adjacent slopes; no significant build-up of eroded materials, debris, or sedimentation; no organic growth on interior surfaces; minimal signs of seepage through unlined channels; limited corrosion, cavitation, or spalling of steel and concrete surfaces. Part/item is functioning optimally.	8 – 10
Good	Moderate deterioration or damage to liners of water conveyances; evidence of minor foundation settlement or deterioration; moderate leakage at joints; evidence of minor erosion or instabilities of embankments or adjacent slopes; slight build-up of eroded materials, debris, or sedimentation; minor organic growth on interior surfaces; signs of seepage through unlined channels; moderate corrosion, cavitation, or spalling of steel and concrete surfaces. Part/item function is not significantly affected however minor repairs may be necessary.	5 – 7
Fair	Large areas of deterioration or damage to liners of water conveyances; evidence of foundation settlement or deterioration; considerable leakage at joints; evidence of significant erosion or instabilities of embankments or adjacent slopes; significant build-up of eroded materials, debris, or sedimentation; build-up of organic growth on interior surfaces; moderate seepage through unlined channels; large areas of corrosion, cavitation, or spalling of steel and concrete surfaces. Part/item function is adequate, however, efficiency and reliability may be affected. Moderate repairs may be necessary.	3 – 4
Poor	Severe deterioration or damage to liners of water conveyances; extensive foundation settlement or deterioration; excessive leakage at joints; significant erosion or instabilities of embankments or adjacent slopes; limited flow or complete blockage due to build-up of eroded materials, debris, or sedimentation; severe organic growth on interior surfaces; excessive seepage through unlined channels; severe corrosion, cavitation, or spalling of steel and concrete surfaces. Part/item no longer functions properly or there is a risk of failure. Replacement or repairs are necessary.	0 – 2

Age - Rating Criteria for Flumes/Open Channels

Age is an important factor when considering part or system upgrade as it can be an indication of performance degradation. As water conveyances age, they become more susceptible to wear due to vibrations, turbulent flow, and severe weather. Not only does increased wear result in operational problems and loss of efficiency, it can also increase the risk of sudden failure.

Age scoring is relatively more objective than other condition parameters. The detailed scoring criterion developed in Chart 2 allows the age score to be automatically generated in the HAP Database by the actual years of the installed part. Channel liners typically have a maximum life span of 25 to 30 years depending on the type of liner material and application process; whereas, structural components (i.e. flume structure) or excavated channel formation can last up to 80 years with routine and proper maintenance. The Age scoring criteria for various parts are shown in Chart 2.

Chart 2 Age Rating Criteria for Flumes/Open Channels		
Age of Flume Structure, Open Channel, Forebay Structure, Desilting Chamber, Foundation or Supports, and Joints	**Age Score**	**Age of Liners**
<30 years	**8 - 10**	<10 years
30-60 years	**5-7**	10-20 years
60-80 years	**3-4**	20-30 years
>80 years	**0-2**	>30 years

Installed Technology – Rating Criteria for Flume/Open Channels

The Installed Technology indicates advancement in flume and open channel design, installation/construction techniques, liner/coating materials and application process, and other materials which may affect the hydraulic, maintenance and reliability performance of water conveyance system. Outdated technology may cause difficulties for supplying replacement parts or performing routine maintenance which can result in prolonged outages.

Scoring the Installed Technology requires historic knowledge of flume and open channel technology advancement and familiarity with industry standards and materials. For example, historically, open channels have been unlined or lined with erodible materials such as sand or gravel. This can lead to a multitude of maintenance issues over time such as severe erosion, water loss due to seepage, buildup of organic material (i.e., weeds), and increased surface roughness. Therefore, channels with liners such as concrete or geomembranes will receive a higher score than unlined channels. The hydraulic modeling and design tool for open flow conveyance systems is another factor to consider for scoring the Installed Technology. With advances in computer modeling, designers are able to provide a more hydraulically efficient arrangement while limiting erroneous design inputs. Other factors to consider are advances in excavation and construction techniques.

The competence, professionalism, and reputation of the original suppliers could also impact the Installed Technology. As compared to large and well-known manufacturers, the parts supplied or installed by small, unknown companies would get lower scores. The Installed Technology scoring criteria for various parts are shown in Chart 3.

Chart 3 Flumes/Open Channels Technology Rating Criteria	
Technology Levels of the Design and Construction	**Score for Installed Technology Level**
The technology has not been changed significantly since the part/item was installed; and the installed technology was supplied by brand name companies with a great reputation	**8 – 10**
The technology has been more or less advanced but no problem to supply the matching parts in next 5-10 years, or the technology change has little effect on the efficiency and reliability of power generation (but may reduce the cost of replacement). The installed technology was supplied by medium companies with good reputation.	**4 – 7**
The installed technology has been phased out, it is a problem to supply parts in reasonable order time, or the technology change has significantly improved the efficiency and reliability of power generation. The installed technology was supplied by small companies with bad reputation.	**0 – 3**

<u>Operating Restrictions - Rating Criteria for Flumes/Open Channels</u>

The Operating Restrictions refers to the current limitations on the operating ranges including flow, head and power capacity. Either under-sized or under-utilized capacity may reduce the overall operational efficiencies and accelerate the deterioration of the water conveyance physical condition. Operational limitations play a role in determining the serviceability of the unit: the greater the limitations, the greater the generation loss.

Operating restrictions can be caused by to two sources:

1) The conveyance system itself. To limit deterioration or to ensure structural safety, the operating flows are constrained due to the limitations of the original design and/or the current deteriorated physical condition. Flow can also be impacted by obstructions in the channels (due to debris or ice) or a reduction of hydraulic area (due to sedimentation or organic material buildup).
2) Environmental restrictions due to habitat maintenance, water quality issues (i.e., Dissolved Oxygen), or fish passage. These restrictions can affect minimum required flows and thus affect the available plant flows. Other environmental restrictions can stem from changes in flow conditions due to climate change or changes in the Probable Maximum Flood (PMF). However, any constraint from other components within the facility, which may affect unit and plant generation, will not be included in the constraints for flume and open channels. For example, if the water in the headwater reservoir is limited due to dam safety concerns, then the dam (not the water conveyance) will receive a lower score for Operating Restrictions.

Chart 4 describes the ratings for Operating Restrictions.

Chart 4 Flumes/Open Channels Operating Restrictions Rating Criteria

Operating Restrictions or Off-Design Conditions	Score for Operating Restrictions
The design standard has no changes, and the original design has no constraints on the required operation.	8 – 10
Minimal restraints: Operations to avoid minor rough zones; operation range can be expanded with revised equipment selection or design.	5 – 7
Moderate restraints: Operations to avoid large rough zones and high vibrations. The operation range and performance can be significantly improved with revised system design.	3 – 4
Severe limitations: The part/item does not meet the operational criteria, performance and reliability are significantly limited if it operates under current environment/requirement.	0 – 2

<u>Maintenance Requirement – Rating Criteria for Flumes/Open Channels</u>

The amount of corrective maintenance that either has been or must be performed is an indication of the water conveyance condition. If the conveyance system has required limited or no maintenance, then that is an indication that the system is in good condition. If a part has required extreme corrective maintenance resulting in unscheduled or forced outages, then the part is considered to be in poor condition.

Other factors to consider for maintenance scoring include:

- Maintenance needs are increasing with time or problems are re-occurring
- Previous failures or issues related to flumes and open channels
- Failures or problems with flumes or open channels of similar design and material

The results of the maintenance history (including routine maintenance and corrective maintenance) are analyzed and applied to Chart 5.

Chart 5 Flumes/Open Channels Maintenance Requirement Rating Criteria	
Amounts of Corrective Maintenance	**Maintenance Requirement Score**
Minimum level (normal condition): A small amount of routine preventive maintenance is required. No corrective maintenance.	**9 – 10**
Low level: Small amounts of corrective maintenance (e.g., less than 3 staff days per part/item per year). Repairs that could be completed during a unit preventive maintenance outage that is scheduled on a periodic basis.	**7 – 8**
Moderate level: Some corrective maintenance that causes extensions of unit preventative maintenance outages.	**5 – 6**
Significant/Extensive level: Significant additional and corrective maintenance is required; forced outage occurs and outages are extended due to maintenance problems.	**3 – 4**
Severe level: Severe corrective maintenance that requires scheduled or forced outages. Repeated forced outages, frequent repairs, abnormal wear to parts/items, and/or labor-intensive maintenance is required.	**0 – 2**

Data Quality – Rating Criteria for Flumes/Open Channels

The Data Quality score reflects the quality of the inspection, test, and measurement results used to evaluate flumes and open channels. The more current and complete the inspection, tests, and measurement results are, the higher the Data Quality scores. The frequency of normal testing is as recommended by industry standards.

Reasonable efforts should be made to perform visual inspections and data collection (measurements, tests, operation logs, maintenance records, design drawings, previous assessment reports, etc.). However, when data is unavailable to score a condition parameter properly, it may be assumed that the condition is "Good" or numerically equal to some mid-range number 3-7. Meanwhile, the Data Quality score is graded low to recognize the poor or missing data.

Qualified personnel should make a subjective determination of the Data Quality scores, considering as many factors as possible. The suggested criteria for scoring the Data Quality are developed in Chart 6.

Chart 6 Flumes/Open Channels Data Quality Rating Criteria

Data Availability, Integrity and Accuracy	Data Quality Score
High – The maintenance policies and procedures were followed by the plant and the routine inspections, tests, and measurements were performed within normal frequency in the plant. The required data and information are available to the assessment team through all means of site visits, possible visual inspections and interviews with experienced plant staff.	**8 – 10**
Medium – One or more of routine inspections, tests, and measurements were completed 6-24 months past the normal frequency, or small portion of required data, information and documents are not available to the assessment team.	**5 – 7**
Low – One or more of routine inspections, tests, and measurements were completed 24-36 months past the normal frequency, or some of results are not available.	**3 – 4**
Very Low – One or more of required inspections, tests, and measurements were completed >36 months past the normal frequency, or significant portion of results are not available.	**0 – 2**

6.0 Condition and Data Quality Indicator

In Table1, the final condition score for flumes and open channels, i.e., the Condition Indicator, *CI*, can be calculated as follows:

$$CI = \frac{\sum_{K=1,M}^{J=1,5} S_C(K,J) \times F(K) \times F(J)}{\sum_{K=1,M}^{J=1,5} F(K) \times F(J)} \qquad (1)$$

The Data Quality Indicator, *DI*, will be the weighted summation of all Data Quality scores received for its associated parts:

$$DI = \frac{\sum_{K=1,M} S_D(K) \times F(K)}{\sum_{K=1,M} F(K)} \qquad (2)$$

Here *M* = the total number of parts associated with a flume or open channel; *K* = the identification No. of parts (from 1 to *M*); *J* = the identification No. of condition parameters (from 1 to 5, respectively for physical condition, age,…); $S_C(K, J)$ = the condition score of a part for one of 5 condition parameters; $S_D(K)$ = the data quality score for a part; *F*(*J*) = the weighting factor for a condition parameter; *F*(*K*) = the weighting factor for a part.

The calculated Condition Indicator from equation (1) may be adjusted by the results of internal inspections and specific testing results that would be performed, since the specific testing would more directly reveal the condition of the water conveyance.

7.0 References

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