Hydrologic Modeling Associated with Permitting an Expansion of a Coal Combustion Products Landfill

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ABSTRACT

Construction of Coal Combustion Products landfills often impact streams and wetlands that are protected by Federal and State Regulations requiring permitting. In addition, landfills require the installation of a liner system over relatively large areas which reduces groundwater recharge causing potential secondary impacts to streams and wetlands in the form of reduced flow. This paper provides an analytical approach to determine potential stream/wetlands impacts by performing a field evaluation of downgradient streams/wetlands to determine the source of hydrology. The method then calculated the existing, and post-development, surface water flows to downgradient streams and wetlands for both short-term storm-events and long-term (annual) conditions. Using this information the design for a landfill expansion included engineering controls so that stormwater could be captured and then discharged either directly or indirectly to the streams and wetlands depending on the existing source of water. Engineering controls included locating sediment basins upstream of the streams/wetlands to store surface water which could then be discharged directly to the stream or discharged to infiltration trenches to provide a groundwater recharge component. A hydrologic budget analysis was performed to demonstrate that the amount of water received by the streams and wetlands after landfill construction is equivalent to the volume of water received prior to construction on both a short-term and long-term basis.

INTRODUCTION

Construction of landfills for the disposal of Coal Combustion Products (CCP) requires the installation of composite liner systems typically over large areas. The liner system results in reduced groundwater recharge which has the potential to impact streams and wetlands downgradient of the proposed landfill expansion. Waste management and surface water protection regulations both require these resources be protected and that potential secondary impacts be evaluated. The following method evaluates the source of the existing stream and wetland hydrology through field evaluation and piezometer installation. The method then calculates the existing and post-development surface water flows to downgradient streams and wetlands for both short-term storm-events and long-term (annual) conditions using HydroCAD and HEC-HMS modeling programs. Using the hydrology evaluation and the modeling data, a hydrologic budget is
developed and utilized to design engineering controls to protect the stream and wetland resources.

PROJECT APPROACH

To address these regulatory concerns, Civil & Environmental Consultants, Inc. (CEC) personnel conducted a field evaluation of the streams and wetlands downgradient from the proposed landfill expansion area to identify the source of hydrology for the wetlands and stream segments in the area of interest. Specifically, the evaluation was intended to determine if the source of water was regional groundwater, transient groundwater, surface water runoff or overbank flooding. The field evaluation also intended to determine if topography concentrated surface water runoff to the resource indicated that surface water was a source of hydrology. The flow at the assessment point was estimated and notes regarding the source of water were recorded. The field evaluation was performed by an experienced wetland scientist and a hydrogeologist. An example of the results of the field evaluation are provided in Table 1.

<table>
<thead>
<tr>
<th>Aquatic Resource Identification</th>
<th>Assessment Point</th>
<th>Classification at Assessment Point</th>
<th>Source of Hydrology</th>
<th>Topography Concentrates Runoff to Resource (Y/N)</th>
<th>Estimated Flow At Assessment Point (GPM)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tributary 1</td>
<td>Ephemeral/ Intermittent Break</td>
<td>Intermittent</td>
<td>Regional Groundwater</td>
<td>X</td>
<td>Y</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 1 – Stream/Wetland Field Assessment

Hydrogeologic investigations were also performed as part of the landfill permit application and utilized to determine the source of hydrology to the streams and wetlands. The investigations included the installation of nested piezometers to determine the elevation of the seasonal high water table and the vertical component of groundwater flow. Nested piezometers in the area of interest indicated that the regional water table occurs within bedrock well below the ground surface. Additionally, comparison of the nested piezometer water levels indicated that the vertical component of the regional groundwater flow is in the downward direction. This information indicates that the higher elevation streams and wetlands in the area of interest are not recharged by the regional water table.

The hydrologic and hydrogeologic evaluations determined the source of hydrology for all of the streams and wetlands to be transient groundwater or surface water, and that the source of hydrology to the aquatic resources was not from regional groundwater in any of the locations.

Surface water flow and precipitation data was also collected to evaluate the sources of hydrology to the streams and wetlands (Figure 1). Surface water flow rate monitoring points were constructed with weirs for estimating flow and measured periodically. While
accurate correlations between precipitation and surface water flow cannot be made due to the intermittent measurements, general conclusions can be made. In general the surface water flow rates are highly variable and dependent on precipitation amounts. This is consistent with surface water flow tied to runoff, and to recharge by transient groundwater flow fed by precipitation.

Figure 1 – Weir and Precipitation Data

This groundwater and surface water information, along with the field observations of the stream and wetland occurrence with respect to topography and drainage, indicate that they are supplied by shallower transient groundwater within the vadose zone as well as surface water runoff or overbank flooding.

Although the streams and wetlands in the areas of interest are not directly fed by regional groundwater they are still affected by local recharge from upgradient areas. As groundwater recharge from precipitation migrates through the vadose zone as transient groundwater, a portion of this water is deflected to surface depressions and stream channels on its way to the regional water table. In this way a percentage of the upland recharge feeds the higher elevation streams and wetlands. This hydrologic conceptual model is illustrated in Figure 2.
In locations where transient groundwater comprises a significant source of water to the streams and wetlands, we evaluated the potential for impacts from reduction of recharge in the upgradient areas. Existing groundwater recharge was estimated in the upland areas of the stream segments and wetlands where transient groundwater is the primary source of water. We then estimated the amount of groundwater recharge based on the proposed landfill expansion. Figure 3 presents the Hydrologic Conceptual Model following landfill development when precipitation that formerly infiltrated into the regional and transient water table now falls on the landfill and is collected in the leachate and surface water management systems.

The difference in flows between pre- and post-development conditions were used to design infiltration trenches to supply additional groundwater recharge to aquatic resources fed by groundwater and to determine additional surface water volumes which need to be directed to aquatic resources fed by a combination of groundwater and surface water. The size of the infiltration gallery was determined so that the combination of post-development recharge from the unlined area and the infiltration gallery is similar to the calculated preconstruction recharge. The water to the infiltration gallery will be supplied by sediment basins that have been designed as part of the overall landfill development plan.
Infiltration trenches were designed to replenish transient groundwater supplies and stabilize base flow in streams. Based on the proposed location of the infiltration trenches in relation to the existing streams, efficient recharge will be provided because the infiltration will occur relatively close to where the runoff is generated, thus limiting evaporative loss and infiltrating more rainfall. Additionally, the base flow to the potentially affected stream is from surface water infiltration to near surface transient groundwater. Based on nearby piezometers, the regional water table occurs at a much lower elevation within the bedrock. Pre-development surface water infiltrates to lower permeable units within the soil horizons and/or to the soil bedrock interface. This transient groundwater then migrates horizontally and discharges to the streams. The proposed infiltration trenches will perform the same function and allow water to infiltrate to the streams in a similar manner, thus maintaining the benthic macroinvertebrate community. Therefore, infiltration can be correlated to stream flow. Figure 4 provides a detail of the infiltration trench design.

![Infiltration Trench Design](image)

In locations where surface water runoff provides a significant source of water to the streams and wetlands, we evaluated the potential for impacts from reduction of surface water runoff in the upgradient areas. Existing surface water runoff was estimated in the upland areas of these stream segments and wetlands to establish a baseline against which the potential reduction in surface water resulting from constructing the landfill liner system can be quantified.

CCP Landfills are typically developed sequentially in phases. The groundwater recharge and surface water runoff to the aquatic resource varies with each phase of landfill development as existing drainage and recharge areas are removed as the landfill liner system is constructed and landfill sedimentation basins are constructed which collect surface water runoff from the landfill. The critical (worst-case) phase in the proposed phasing development plan for each aquatic resource was considered in evaluating both groundwater recharge/infiltration and surface water runoff. The evaluation was conducted by means of model simulations discussed in the following section.

**MODEL SELECTION**

There are several methods available that can be used to model the potential reduction of groundwater recharge to streams and wetlands downgradient of the proposed landfill
expansion resulting from installation of the landfill liner system. CEC determined that the following modeling programs were suitable to perform these analyses:

- HydroCAD Stormwater Modeling 10.0, HydroCAD Software Solutions LLC, 2011.

As stated in their technical literature, HydroCAD is a Computer Aided Design system for modeling the hydrology and hydraulics of stormwater runoff. It is based largely on the hydrology techniques developed by the Soil Conservation Service (SCS/NRCS), combined with other hydrology and hydraulics calculations. For a given rainfall event, these techniques are used to generate hydrographs throughout a watershed. Typically, this allows the engineer to verify that a given drainage system is adequate for the area under consideration, or to predict where flooding or erosion is likely to occur.

HydroCAD is a widely used and appropriate model to evaluate the surface water hydrology associated with the proposed expansion related to specific storm events. The limitation of HydroCAD is that a 6-hour time interval is the shortest storm that can be accurately analyzed. While this model is useful for defined storm events, it is limited in evaluating long term surface water flows. Therefore, HydroCAD was selected and utilized to estimate the pre and post development peak and 4 day flows based on a relatively short time interval which recurs frequently throughout a year.

The technical literature for HEC-HMS states: “The Hydrologic Modeling System (HEC-HMS) is designed to simulate the complete hydrologic processes of dendritic watershed systems. The software includes many traditional hydrologic analysis procedures such as event infiltration, unit hydrographs, and hydrologic routing. HEC-HMS also includes procedures necessary for continuous simulation including evapo-transpiration, snowmelt, and soil moisture accounting. Advanced capabilities are also provided for gridded runoff simulation using the linear quasi-distributed runoff transform (ModClark). Supplemental analysis tools are provided for model optimization, forecasting streamflow, depth-area reduction, assessing model uncertainty, erosion and sediment transport, and water quality.

The HEC-HMS model can simultaneously evaluate the effects of a series of precipitation events on surface water runoff, evapotranspiration, and groundwater infiltration in a defined watershed area, while accounting for storage of water within the soil. This capacity allows HEC-HMS to model the recharge areas which involve either groundwater supply or a combination of groundwater and surface water supply. The model can also calculate the average annual volumes of groundwater infiltration and surface water runoff in the recharge areas during a representative precipitation year. This annual capability is much more useful in evaluating base flows to aquatic resources and sediment basins or infiltration trenches in pre and post development conditions. For these reasons HEC-HMS was selected as the primary model for predicting the potential impacts to streams and wetlands downgradient of the proposed landfill expansion resulting from installation of the landfill liner system potentially reducing groundwater recharge to these features.
CALCULATIONS

As noted above, depending on the source hydrology of each aquatic resource, HydroCAD and HEC-HMS modeling programs were used to evaluate the recharge conditions at the critical phase for each location.

**HydroCAD Modeling**

Based on the field investigation and review of the topography, it was determined that the surface water recharge of several tributaries may be impacted by the proposed construction of the landfill expansion. The approximate surface water recharge areas under existing conditions for each tributary were estimated according to the site conditions and upslope topography. The proposed phasing development plan was then reviewed to determine the phase during which the surface water runoff to each aquatic resource would be minimized. This minimum phase was considered the worst-case, or critical, phase for that aquatic resource. The surface water calculation was then performed for this critical phase to determine the maximum reduction in observed surface water recharge to each aquatic resource.

The storm event chosen for HydroCAD modeling was a 1-year, 6-hour storm. The 1-year recurrence storm is the shortest recurrence interval available in the National Oceanic and Atmospheric Administration (NOAA) online Atlas 14 data and the 6-hour time interval is the shortest storm that can be analyzed using HydroCAD software. Therefore, the 1-year, 6-hour storm was selected as the shortest return storm capable of being quantitatively analyzed.

The precipitation amount (1.5 inches) for the 1-year, 6-hour storm event was based on (NOAA) online Atlas 14 data for the landfill area. Peak flow rates were compared to evaluate the reduction in peak flow and associated peak velocity in the receiving stream, which is beneficial in reducing stream channel erosion and scour. The total flow volume was also calculated over a 4-day period following the 1-year, 6-hour storm event to provide a comparison of total stream recharge at each aquatic resource.

HydroCAD 10.0 was used to route the 1-year, 6-hour storm through the existing drainage areas based on the existing topography and through the proposed drainage areas based on the final cover grading plan.

Table 2 below presents the peak flow and the 4 day flow volume from the 1-year, 6-hour storm for both existing conditions and critical phase conditions at a typical stream and wetland location. For the HydroCAD calculations, if a proposed sedimentation basin outlet is directly upstream of the aquatic resource, surface water from the sedimentation basin is considered part of the total runoff directed to the aquatic resource. Additionally, the drainage areas of temporary berms (see discussion in the HEC-HMS modeling section below) are included as appropriate. These flow calculations should not be considered for evaluation of volume balance where groundwater recharge is present as HydroCAD cannot account for diversion of water from the sedimentation basins to infiltration trenches or other surface water recharge points.
Aquatic Resource | Peak Flow for Existing Conditions, cfs (l/s) | Peak Flow for Proposed Critical Conditions, cfs (l/s) | 4 Day Flow Volume for Existing Conditions, cf (cm) | 4 Day Flow Volume for Proposed Critical Conditions, cf (cm)
---|---|---|---|---
Tributary 1 | 4.0 (110) | 0.5 (14) | 11,000 (310) | 18,000 (510)
Wetland 1 | 1.0 (28) | 0.5 (14) | 3,000 (85) | 800 (22)

Table 2 – HydroCAD Calculation Summary

Based on the HydroCAD evaluation of aquatic resources fed only by surface water, Tributary 1 will receive adequate surface water recharge. However, Wetland 1 has a deficit in the 4-day cumulative flow; therefore, supplemental flow will need to be directed to the wetland.

**HEC-HMS Modeling**

Based on the field investigation and review of the topography, it was determined that the groundwater recharge of several aquatic resources could potentially be impacted by the proposed construction of the landfill expansion. The approximate groundwater and surface water (where applicable) recharge areas for each tributary were estimated according to the site conditions and upslope topography.

HEC-HMS requires site-specific data inputs for rainfall, evapotranspiration, and soil properties. To evaluate the long term base flow conditions, CEC used the annual precipitation data over a 10-year period (January 2005 through December 2015) obtained from NOAA’s NCDC database. The precipitation for each year was totaled and an average annual precipitation for the 10-year span was calculated. The precipitation data for the year 2006 was modeled because it was closest to the 10-year average. Evapotranspiration was estimated to be 44.5% of the precipitation, based on an estimated Mean Annual Ratio of Actual Evapotranspiration to Precipitation for the landfill area which was obtained from Figure 13 originally published by the Journal of the American Water Resources Association (JAWRA). Hydraulic conductivity properties of in-situ soils were determined by field permeameter testing performed at several locations representing different soil types. The infiltration characteristics of soil outside the area where hydraulic conductivity testing was conducted were considered to be similar to the average properties of the soil within the test area.

The HEC-HMS model was first applied to the recharge areas for the location where the infiltration testing was performed. The ratio between each parameter (infiltration, runoff, and evapotranspiration) and the total rainfall in the known areas was then calculated and applied the ratio to similar areas. This approach is justified based on the similar soil types within each drainage boundary and that the percentages of infiltration, evapotranspiration and runoff can be estimated for nearby, very small watersheds. A weighted average was calculated using the known areas and these weighted percentages were then used to calculate the infiltration and runoff for the recharge areas of the other tributaries as a weighted ratio of the total rainfall during existing and critical phase conditions.
The initial calculations for each aquatic resource of interest were performed assuming no additional flow from proposed sedimentation basins. This allowed for the determination of the deficit for total annual volumes of both groundwater and surface water recharge at each aquatic resource. Once these calculations were performed, temporary berms were designed, as needed, to convey additional flow to sedimentation basins during the respective critical phases to provide adequate surface water volume for all aquatic resources. As additional landfill areas are covered and the associated runoff is directed to the sedimentation basins, the temporary berms will be abandoned.

Recharge Deficit Evaluation

Table 3 presents a typical summary of the additional surface water and groundwater recharge flows required at an aquatic resource downgradient of a sedimentation basin. This shows the available water volume on an annual basis and the water volume required by the aquatic resource recharge point.

<table>
<thead>
<tr>
<th>Critical Phase</th>
<th>Sedimentation Basin 1, Annual Volume, cf (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Available Volume</td>
<td>1,638,000 (46,400)</td>
</tr>
<tr>
<td>Stream Runoff</td>
<td>1,058,000 (29,900)</td>
</tr>
<tr>
<td>Stream Infiltration</td>
<td>85,000 (2,400)</td>
</tr>
<tr>
<td>Stream 2 Runoff</td>
<td>135,000 (3,800)</td>
</tr>
<tr>
<td>Stream 2 Infiltration</td>
<td>115,000 (3,300)</td>
</tr>
<tr>
<td>Volume Surplus</td>
<td>245,000 (6,900)</td>
</tr>
</tbody>
</table>

Table 3 – Recharge Deficit Summary

Water from the sedimentation basins will be conveyed via pipe to either the appropriate surface discharge point or to an infiltration trench or gallery. Flows will be controlled using valves in the conveyance pipes, especially where it is necessary to split the flow from a single sedimentation basin among multiple recharge points. Rip-rap aprons or other similar, appropriate erosion and sedimentation controls will be installed at surface discharge points.

The infiltration trenches were designed assuming that peak daily infiltration is proportional to peak daily rainfall. It was assumed that the estimated peak daily infiltration volume must be handled by the trench in an 8-hour infiltration time period. Trenches were designed 3-feet wide and the rate of infiltration through underlying soil was conservatively assumed to be equal to the slowest observed infiltration rate during field testing. Based on these parameters, the required length of infiltration trench for each infiltration location was calculated.
SUMMARY AND CONCLUSIONS

A hydrologic budget analyses was performed to evaluate potential indirect impacts to streams and wetlands from the loss of the recharge area resulting from the installation of the liner system in the ash disposal expansion area. This hydrologic budget analyses addressed streams and wetlands that could potentially be impacted by installation of the liner system. Depending on the source of hydrology, the budget analyses included surface water runoff changes, infiltration volume changes, or both, for pre and post development conditions.

Table 4 provides a summary for a typical aquatic resource at the critical phase of development affecting drainage/recharge, and calculation results for long term annual flows pre and post development (drainage area, runoff quantity, infiltration quantity).

<table>
<thead>
<tr>
<th>Pre-Development Recharge Area, acre (ha)</th>
<th>Post-Development Critical Phase, acre (ha)</th>
<th>Pre-Development Runoff Quantity (Annual), cf (cm)</th>
<th>Post-Development Runoff Quantity (Annual), cf (cm)</th>
<th>Additional Runoff Quantity (Annual), cf (cm)</th>
<th>Pre-Development Infiltration Quantity (Annual), cf (cm)</th>
<th>Post-Development Infiltration Quantity (Annual), cf (cm)</th>
<th>Infiltration Trench Quantity (Annual), cf (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.5 (5.1)</td>
<td>10.3 (4.2)</td>
<td>1,300,000 (39,400)</td>
<td>45,000 (1,400)</td>
<td>1,250,000 (38,000)</td>
<td>615,000 (18,700)</td>
<td>510,000 (15,300)</td>
<td>105,000 (3,400)</td>
</tr>
</tbody>
</table>

1. Volume of surface water which must be routed from the adjacent sediment basin.

Table 4 – Long-Term Flow Summary

For the aquatic resources for which surface water runoff is a source of hydrology, a short term storm event was evaluated. The short term storm event peak flows declined during post development conditions which reduces the potential for erosion and scouring. The short term 4 day flows typically increased during post development, which is preferable because it provides flow to the small upland stream segments for a longer period.

For the aquatic resources that have a groundwater or combination of groundwater and surface water runoff source of hydrology, an annual series of rainfall events to reflect base flow conditions was evaluated. The evaluation included both runoff and infiltration volumes on an annual basis. The post development runoff quantity increased to each location as surface water was diverted from sedimentation basins as needed to maintain or increase the runoff recharge for each aquatic resource. The reduction in infiltration from constructing the liner system was compensated by designing infiltration trenches which will take a portion of the water collected in the designed sediment basins and sediment traps to recharge the groundwater.
The results of the hydrologic budget analyses is that the loss of recharge resulting from the construction of the landfill liner system will not have an adverse impact on perennial streams and wetlands around the landfill expansion area.

REFERENCES

HydroCAD Stormwater Modeling 10.0, HydroCAD Software Solutions LLC, 2011.


National Oceanic and Atmospheric Administration (NOAA) Online Atlas 14 Data.