Openlands – Tool Application Final Report

Ecosystem Restoration and Hydrology Changes Tool Application and Analysis

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Sign-off Sheet

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Executive Summary

Stantec Consulting Services Inc. (Stantec) partnered with Wills Burke Kelsey Associates (WBK) and Huddleston McBride Land Drainage Co. to help Openlands develop and apply a tool and methodology to determine the storm water benefit (specifically quantity and/or rate of release) related to landscape-level ecosystem restoration. The tool was applied at two existing Openlands restoration project sites, Deer Grove East and Tinley Creek West Wetlands, for both pre-restoration and post-project conditions.

The modeling tool was developed using the SWMM software package and commonly available data sets such as site topography, soils, precipitation, vegetation cover, impervious surfaces, and drain tile information. Model results were calibrated using well data available at both sites. Well data proved very important for calibration and verification of the post-restoration results. The modeled results reasonably match the observed data for a majority of the simulation events. The results of the sub-surface calibration can be considered successful in that the data provided helpful information in order to increase the certainty in the models. As such, above-ground flow monitoring and monitoring data of pre-restoration conditions would assist in isolating the differences in results and refining the assumed parameter inputs.

Both sites were modeled as a number of interconnected sub-catchments, with the possibility that surface runoff and shallow infiltration from a sub-catchment will flow within the site to another sub-catchment. This surface runoff is one component in accounting for all of the water that falls on-site in the form of precipitation, and is highly dependent on the intensity of a storm which is independent of the restoration. Other components are deep infiltration and tile flow among others. The locations where water leaves the site were identified in order to measure the overall effectiveness of the restoration. This was done by comparing the modeled volume of water that actually leaves the site on a yearly or model-period basis for both pre- and post-project conditions.

The model was run as a continuous simulation of the growing seasons in 2014 and 2015. Model results were compared between the pre- and post-restoration scenarios. The major expected hydrologic and hydraulic effects of landscape scale ecosystem restoration, such as increases in deep evapotranspiration and reductions in groundwater drain tile outflow were confirmed by the models. The models also produced a change in local surface runoff based on the change in vegetation type and surface roughness. Model results show the surface runoff decreased internally on the Deer Grove East site when roughness increased and local surface runoff increased at Tinley Creek West when the landuse changed from woods to wetland vegetation.

The increase in wetland vegetation directly impacted the surface runoff volume within the Deer Grove East Site, reducing local surface runoff volume internally on the site by 20%. Model results show surface runoff within the site decreased by 6.5 million gallons during the 2014 growing season and by almost 4.5 million gallons in 2015. Both periods generally produced typical

monthly rainfall values observed in Illinois. Accounting for all the aspects of the hydrologic water budget and the removal of drain tile, discharge volumes of flow leaving the site is reduced by approximately 40 million gallons of water for both 2014 and 2015 model runs combined. The decrease in localized surface runoff volumes also corresponded to the decrease in rate/timing of storm water release from the Deer Grove East modeled areas between pre- and post-project conditions.

Table E.1 Deer Grove East - Modeled Discharge Volumes Leaving Site

Site Discharge Volumes – Deer Grove East	
Scenario	**Volume (MG)**
2014 Pre-Restoration	21.5
2014-Post-Project	1.7
2015 Pre-Restoration	20.3
2015 Post-Project	0.7

The surface water runoff generated internally within the Tinley Creek West site increased within the hydrologic model when surface roughness decreased between pre- and post-project conditions. Despite the cumulative increase in local surface runoff, analysis of Tinley Creek's modeled outfall locations indicate that the total volume of water leaving the site throughout the year is reduced due to the hydrologic and hydraulic changes associated with the restoration projects. The overall reduction in site discharge volume is due to increased evapotranspiration (from increased root depths) and a decrease in outflow from drain tiles. Accounting for all the aspects of the hydrologic water budget and the removal of drain tile, discharge volumes of flow leaving the site is reduced by approximately 181 million gallons of water for both 2014 and 2015 model runs combined.

Table E.2 Tinley Creek West – Modeled Discharge Volumes Leaving Site

Site Discharge Volumes – Tinley Creek West	
Scenario	**Volume (MG)**
2014 Pre-Restoration	219.7
2014-Post-Project	147.5
2015 Pre-Restoration	179.5
2015 Post-Project	70.2

The final results of the two models show the hydrologic effects of restoration are expected to be a site-specific balance of drain tile removal and a change in vegetation. From a surface runoff perspective, the Tinley Creek West model results show that in the removal of second-growth trees and conversion to grasslands, some more intense rainfall events will naturally generate more on-site surface runoff and depending on proximity to overall site exit points, may actually increase offsite surface outflow for particular storms. However, for small and more frequent rainfalls this was not typically observed. On an annual basis, reductions in outflow volume from both restoration sites were significant. If clearing trees is part of the restoration, adequate surface water control may be included as part of the project in the form of creating closed depressions and defined, stabilized outflow points to account for the increased peak flows during rainfall events with high volumes and intensities.

The model developed for this project is a successful technical tool and a viable means of quantifying hydrologic changes resulting from landscape scale ecosystem restoration. The tool confirms these important environmental projects do have an appreciable effect on hydrology. Future restoration projects like the ones at Deer Grove East and Tinley Creek West will likely experience similar hydrologic benefits such as increased evapotranspiration and decreased discharge volumes of flow leaving the restoration sites. The reduction in storm water volume discharging from the restoration sites means that more water is being retained on-site where it is either evaporated, infiltrated or maintained as surface storage. Application of a tool similar to the models developed for Deer Grove East and Tinley Creek West could assist in predictive scenarios for future restoration sites by updating the hydrologic and hydraulic model components such as vegetation and drain tile modification.

1.0 BACKGROUND - PROJECT PURPOSE AND APPROACH

The purpose of the project is to develop a tool or methodology that users may implement to determine if there is a quantifiable storm water benefit (specifically quantity and/or rate of release) related to landscape-level ecosystem restoration. This report includes a summary and documentation of Stantec's work to develop that tool including the process followed and results for two test sites, Deer Grove East and Tinley Creek West Wetlands.

The team first reviewed existing data relevant to the two test sites and conducted a search on peer reviewed literature associated with existing tools or models and published methodologies. The review focused on tools that were data-driven, replicable, practical, and based on accepted, peer-reviewed methodologies. A preliminary hydrologic assessment methodology was developed, primarily based on water budget and mass balance approaches. A model-based workflow for quantifying water budget inputs and outputs and hydrologic/hydraulic processes was developed related to landscape-level ecosystem restoration, after which case studies were run on test sub-watersheds on the Deer Grove East and Tinley Creek West Wetlands sites. Stantec, its partners (Wills Burke Kelsey Associates (WBK) and Huddleston McBride Land Drainage Co.), and Openlands assembled for a conference on Tuesday, January 12, 2016 to discuss and review the methodology recommendations and to review the case study results. A technical memorandum was developed summarizing the literature search, recommended methodology development, recommended model selection, and technical aspects of recommended model construction and parameterization (Stantec 2016). The recommended approach technical memorandum is included in Appendix A. The recommended model was chosen to be applied to the Deer Grove East and Tinley Creek West Wetlands sites to simulate pre-restoration and post-project conditions.

1.1 TOOL SELECTION

Stantec selected a tool for use that will account for volume and flow change quantification as they relate to wetlands hydrology and be functional with respect to the types of input data typically associated with wetland restoration. As mentioned in the Recommended Approach Technical Memorandum, the Storm Water Management Model (SWMM) developed by the United States Environmental Protection Agency (USEPA) is suggested for volume and flow change quantification as part of the defined approach for the Openlands wetland restoration projects.

The model construction and parameterization described in this report took place within the SWMM software package (current version 5.1.010). The SWMM model is a dynamic rainfall-runoff-routing simulation tool that allows for unsteady, non-uniform flow routing. It was used to track the volumes and flows of the hydrologic cycle for a long-term (continuous) simulation.

2.0 TOOL APPLICATION DEVELOPMENT

Stantec and its team members then collected data and created inputs for model parameters. The data used for this project is typically available for most areas, allowing users to apply the tool to analyze and quantify the volume and flow through sites like the existing Openlands project areas for both pre-restoration and post-project conditions. Stantec understands that Openlands would like to use the approach and tool for future wetland restoration project planning and evaluation, so consideration was given to cost, repeatability and ease of use when acquiring data. A tool may be developed for future restoration sites using the SWMM software package and data sets such as aerial imagery, site topography, soil, precipitation and evaporation data, and subsurface hydraulic information related to drain tile, pipes or ditches (sizes, shapes, invert elevations, etc.). Model results can then be calibrated using available observed monitoring data. The following sections describe the tool's conceptual water budget inputs, calculations, and how it was applied.

2.1 CONCEPTUAL WATER BUDGET

The recommended approach methodology takes processes of the hydrologic cycle and relates them to components of the SWMM computer model to form a conceptual water budget. The water budget/mass balances are critical for understanding system hydrology. Volume quantification involves accounting for the total water budget and mass balance of the hydrologic cycle within a watershed following the general equation below.

$$\Delta S = [P + S_i + G_i] - [ET + S_o + G_o]$$

where: ΔS = change is system storage
P = precipitation
S_i = surface flow in
G_i = groundwater flow in
ET = evapotranspiration
S_o = surface flow out
G_o = groundwater flow out

Precipitation (SWMM rain gage element) generates time-varying data which is received by a land surface component (SWMM sub-catchment element). Applying the land surface characteristics (user inputs such as slope, percent impervious, soil parameters, etc.), precipitation is then converted to rainfall interception (initial abstraction), evaporation of standing surface water, infiltration into unsaturated soil layers, and surface runoff (nonlinear reservoir routing of overland flow) generated by precipitation excess (rainfall less infiltration, evaporation, and initial abstraction). The surface runoff is typically conveyed hydraulically through a transport network of open channels and pipes (SWMM node and link elements). The infiltration can be routed to the sub-surface via groundwater conveyance (SWMM aquifer element) which can then interflow with the surface flows and/or seep out into deeper ground levels. A schematic of SWMM hydrologic and hydraulic processes is presented in Figure 1.

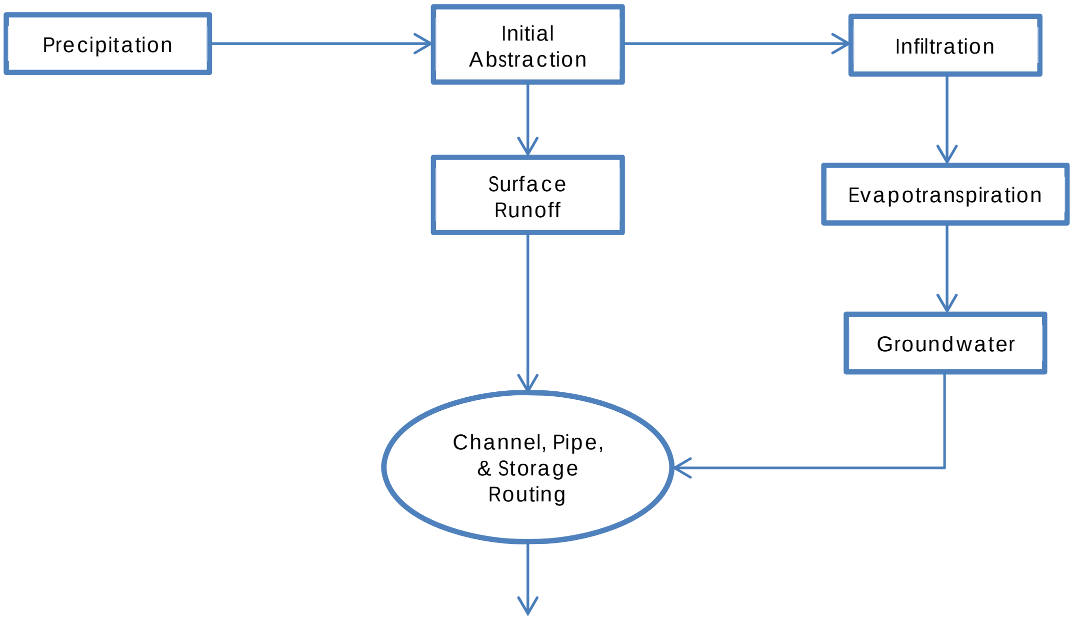


Figure 1. Processes modeled by SWMM. Modified from Rossman (2015).

2.2 EXISTING DATA ACQUISITION

2.2.1 Precipitation

The tool utilizes a long-term simulation to account for varying degrees of soil saturation and groundwater flows, so several months of continuous storm event data over multiple years is desired. Because the simulation focused on months occurring late-spring through early-fall (i.e. the growing season), obtaining quality data during this timeframe was important.

The United States Geological Survey (USGS) provides free observed rain data at locations near the existing Openlands sites. The USGS rain gage at Sundling Junior High School in Palatine, Illinois was used for the Deer Grove East wetlands modeling. The rain gage is approximately one mile south of the Deer Grove East Forest Preserve and records precipitation data in 5-minute increments. Fifteen-minute precipitation data from the USGS rain gage in Frankfort, Illinois was used to model the Tinley Creek site. This gage is approximately five miles from the Bartel Grassland portion of the Tinley Creek Wetlands. Table 1 provides more information on the precipitation data used.

Table 1 Precipitation Data Used

Openlands Site	USGS Rain Gage Location	USGS Gage Number	Data Date Range
Deer Grove East	Sundling Junior High School – Palatine, Illinois	420745088025901	3/7/2014-10/30/2014 3/2/2015-10/31/2015
Tinley Creek West	Frankfort, Illinois	413102087510901	3/1/2014-10/31/2014 3/1/2015-10/31/2015

2.2.2 Evaporation

Evaporation data was obtained from the Illinois State Water Survey (ISWS) – Prairie Research Institute through the Water and Atmospheric Resources Monitoring Program (WARM) (http://isws.illinois.edu/warm/stationmeta.asp?site=STC&from=wx). Historical daily total potential evapotranspiration (ET) data from the St. Charles station was used for both the Deer Grove East and Tinley Creek West models. The weather station is approximately 23 miles from Deer Grove East and 40 miles from the Tinley Creek West Wetlands. The St. Charles site represents the location closest to both Openlands sites with evapotranspiration data. The St. Charles site is also in a physiographic location similar to the sites relative to urban areas and Lake Michigan. The data obtained from this station was used to develop a number of inputs (temperature, wind speed etc.) that is then used to calculate the pan evapotranspiration using the Penman Monteith equation. Table 2 provides more information the weather station used for evaporation.

Table 2 Evaporation Data Used

Openlands Site	Weather Station	Data Date Range
Deer Grove East	St. Charles Latitude: 41.9044 Longitude: -88.3608	12/1/2011-12/31/2015
Tinley Creek West	St. Charles Latitude: 41.9044 Longitude: -88.3608	12/1/2011-12/31/2015

2.2.3 Land Surface Layer Data

Surface LiDAR data obtained by Continental Mapping Consultants was used to determine stage-storage curves for wetland areas and land surface layer characteristics for sub-catchment parameter inputs within the Deer Grove East project area. The sub-catchment areas, average slope, and overland flow paths were delineated using the existing topography (1-foot contour data). A digital elevation model (DEM) surface was created from 1-foot contours received from the Forest Preserve District of Cook County for the Tinley Creek West location. This surface was used to delineate drainage areas, determine depressional storage, and calculate average slopes for all Tinley Creek West sub-catchments.

Google Maps and ESRI provided aerial imagery were used to estimate surface roughness, depression storage, and percent imperviousness values for each sub-catchment.

A vegetation map titled "Plant Community Management Units" from the Deer Grove East Long-Term Management Plan describes the vegetation types and their location within the wetlands. Figure 2 shows the Deer Grove East Plant Community Management Units map. The vegetation data helps to derive a species root depth. A Civil3D file containing Exhibit B titled "Restoration Plant Communities Map" from Living Habitats' Tinley Creek West Wetlands 2014 Monitoring Report was used to calculate the Manning's n values, root depth, and crop coefficients for the post-restoration Tinley Creek West sub-catchments. Figure 3 shows the Tinley Creek Vegetation. Values for the pre-restoration conditions were calculated in a similar manner using a pre-restoration drawing file. Parameters are calculated using a weighted area average based on land cover type.

Figure 2 Deer Grove East Plant Community Management Units

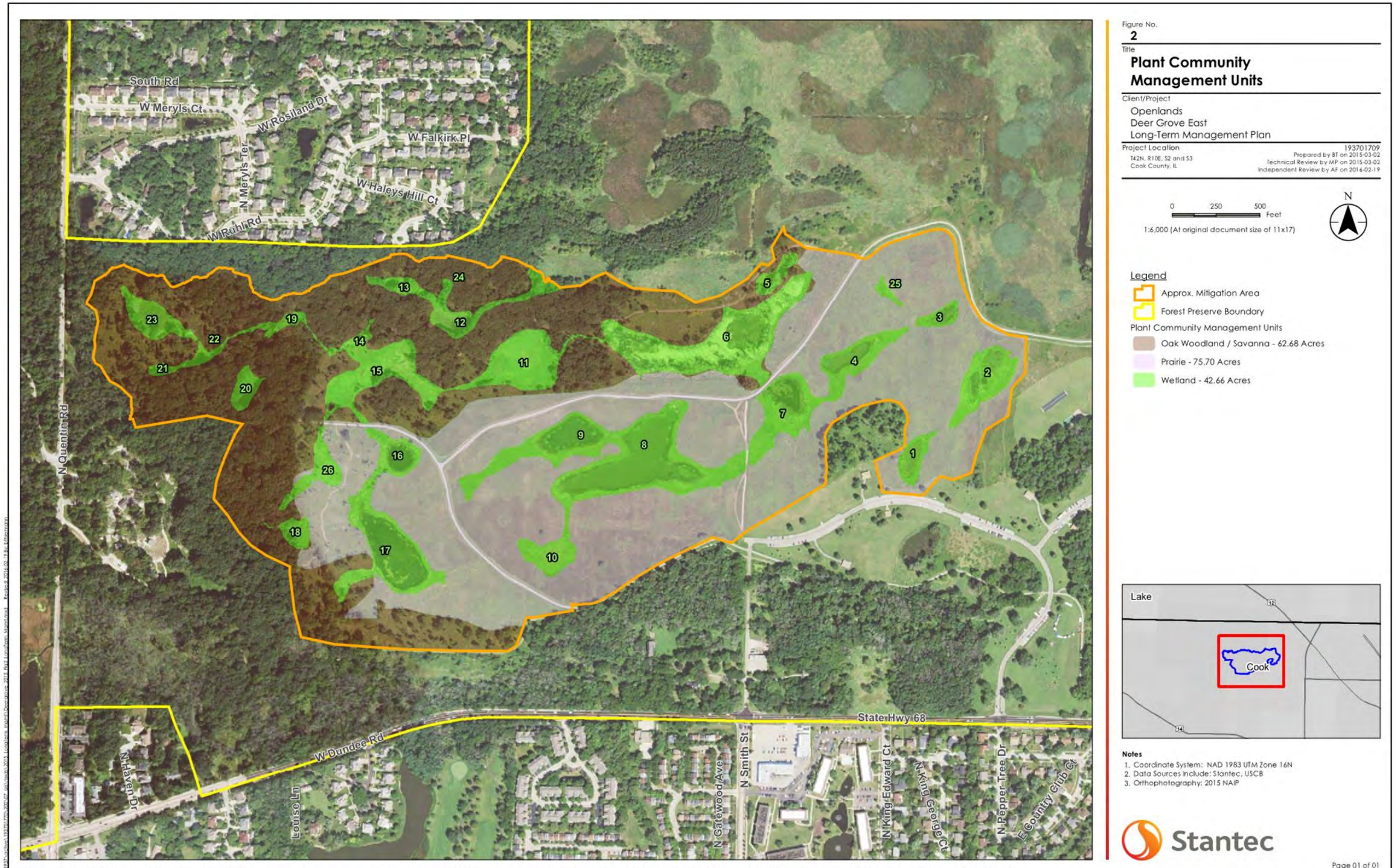
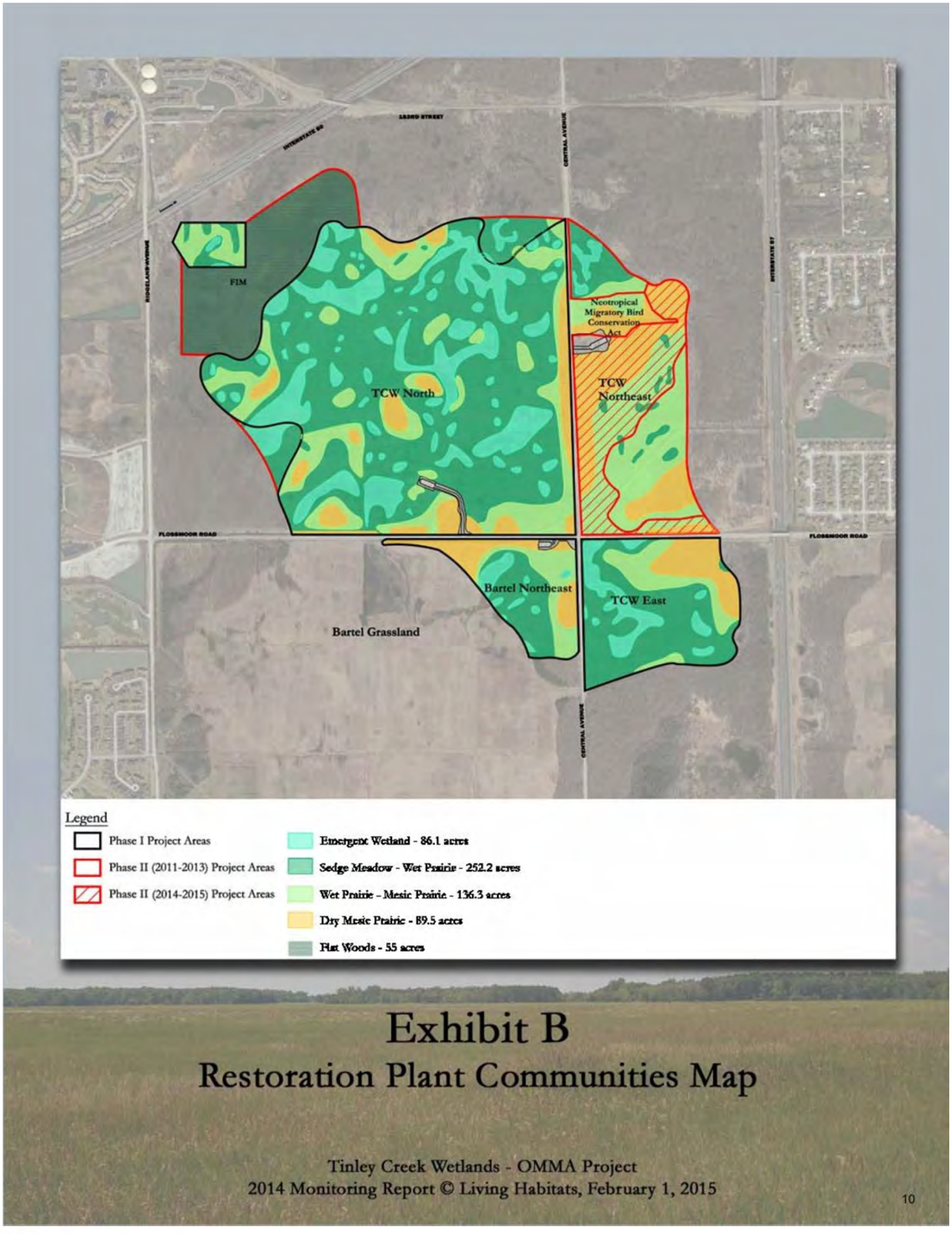


Figure 3 Tinley Creek West Restoration Plant Communities Map



2.2.4 Sub-Surface Layer Data

The SWMM infiltration and sub-surface aquifer calculations require inputs for specific soil characteristics. For approximate soil types and their respective values, existing soil data were obtained through United Natural Resources Conservation Service (NRCS). The NRCS SSURGO database contains information about soil as collected by the National Cooperative Soil Survey.

The sub-surface layer of the SWMM model utilizes several pieces of information collected from the restoration areas through the years. Long-term monitoring wells and their data are available for several time periods at the Openlands project sites. The data at each well provides an indication to where the bottom of the aquifer is located and the approximate starting point for a water table elevation. The monitoring wells also offer existing data to calibrate against.

Finally, an existing drain tile review was performed using the Existing Drain Tile Investigation Modification and Abandonment Plans (Huddleston McBride, 2010). The existing data offers tile location, size, conditions and the approximate depth of the invert elevation below ground. Each piece of drain tile information contributes to the modeling of the sub-surface aquifer layer and accounting of groundwater flow.

2.3 MODEL CONSTRUCTION

As mentioned in the Existing Data Acquisition Section, the majority of the visible model was constructed from aerial imagery, topographic survey data, and the Openlands Drain Tile Investigation Plans. The models were set up using the North American Datum of 1983 (NAD83) Illinois East State Plane Coordinate System. Appendix B contains figures highlighting the setup of the Deer Grove East model sub-catchments, wetland areas, and flow routing network within the geographic information system (GIS) program ArcGIS 10.2.2, and subsequently, SWMM.

2.3.1 Site Descriptions

The Deer Grove East site modeled contains about 220 acres of watershed area comprised of rolling terrain with depressed wetland areas. The modeled Tinley Creek West site covers about 1,260 acres of generally flat terrain. Both sites post-restoration conditions contain a combination of woods, grass, and wetland vegetation.

2.3.2 Hydrologic and Hydraulic Network

The model hydraulic network and sub-catchment delineations were built on top of geo-referenced images of the project sites so contributing areas within the project sites could be accounted for. Each of the sub-catchments within the study areas were delineated using existing topography. The delineation scale between the two Openlands sites was different due to the nature of the topography within the project limits. The Tinley Creek West project area has a minimal change in elevation so the sub-catchments tend to have a higher acreage with lower percent slopes. The Deer Grove East study area has an undulating and more dissected terrain containing over 20 wetland areas in post-restoration conditions. The sub-catchment sizes for this site were finer to account for the routing and storage.

2.3.2.1 Wetlands

The wetland areas of Deer Grove East were modeled as storage nodes. Each storage node utilized a tabular storage curve. Depth/area storage curves were developed using the existing contours from the survey data. For places where the Existing Drain Tile Investigation Modification and Abandonment Plans showed altered topography, changes were applied to the stage-storage curves for the post-restoration conditions. Each storage facility used a weir to represent an outlet to surface overland flow, which was modeled as trapezoidal channels with pertinent geometry obtained from the survey contour data.

2.3.2.2 Drain Tile

The Existing Drain Tile Investigation Modification and Abandonment Plans offers a table with data showing tile location, size, conditions and the approximate depth of the invert elevation below ground. This information was used to construct the tile network in SWMM using circular conduits.

The groundwater option within a SWMM model requires the user to create aquifers. This component is necessary to model the long term effects of the hydrologic cycle. Although there is not a direct input for creating drain tiles, the team calculated coefficients from Hooghoudt's Equation (using the form as provided in the EPA SWMM Reference Manual – Volume I – Hydrology) in order to simulate the effects of the tile drainage. To maintain simplicity within the model, only the main drain tile trunks were modeled, typically assuming a lateral drain spacing of 50 feet. Figure 4 is a summary of Hooghoudt's Equation used to model drain tile hydraulics.

Figure 4 Equation and Sketch of variables used in Hooghoudt's calculation for drain tile

$$f_G = A1(d_L - h^*)^2 - A2 + A3 d_L h_{SW} \quad (5\text{-}38)$$

where

$A1 = 16K_S/L^2$,

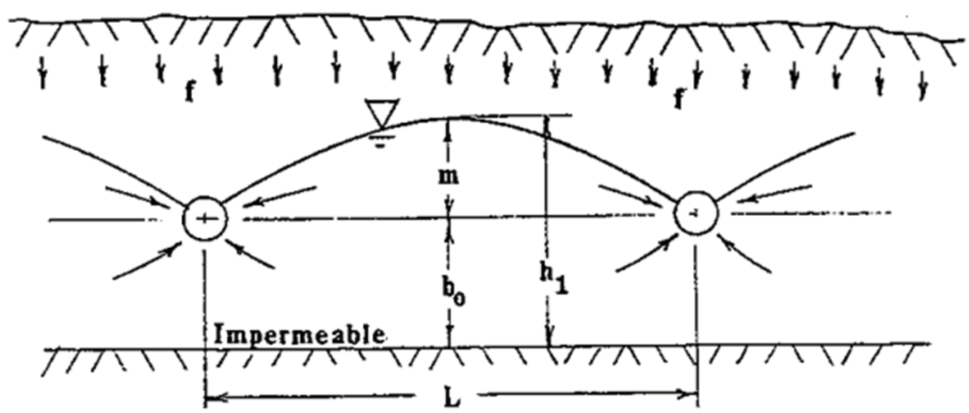
$B1 = 2$,

$A2 = A1 D_e b_0$,

$B2 = 0$,

$A3 = A1(D_e/b_0)$,

h^* is set equal to b_0 and a constant value of h_{SW} only slightly higher than b_0 is used.



2.3.3 Simulation Options

The SWMM simulations were set up to use the Dynamic Wave routing method, run the rainfall/runoff, groundwater, and flow routing process models, and utilize the Modified Green-Ampt infiltration model to account for each part of the hydrologic and hydraulic processes. These processes include precipitation, initial abstraction, infiltration, evaporation and evapotranspiration, surface runoff, groundwater, and hydraulic network routing.

Two separate long-term continuous simulations began on March 15th of 2014 and 2015. Both simulations ended on November 1st of their respective years generally corresponding to the duration of the growing season. Reporting began for each simulation on April 1st. The buffer time between the analysis starting date and reporting starting date allows the model to adjust the initial starting assumptions and get primed to account for varying degrees of soil saturation and groundwater flows. To match the rainfall data, runoff and reporting time steps were set to 5 minutes. Figure 5 summarizes the options used for one of the Deer Grove East model simulations.

Figure 5 Simulation Analysis Options Summary

```
****************
Analysis Options
****************
Flow Units ............... CFS
Process Models:
  Rainfall/Runoff ........ YES
  RDII ................... NO
  Snowmelt ............... NO
  Groundwater ............ YES
  Flow Routing ........... YES
  Ponding Allowed ........ NO
  Water Quality .......... NO
Infiltration Method ...... MODIFIED_GREEN_AMPT
Flow Routing Method ...... DYNWAVE
Starting Date ............ MAR-15-2015 00:00:00
Ending Date .............. NOV-01-2015 00:00:00
Antecedent Dry Days ...... 0.0
Report Time Step ......... 00:05:00
Wet Time Step ............ 00:05:00
Dry Time Step ............ 00:05:00
Routing Time Step ........ 5.00 sec
Variable Time Step ....... YES
Maximum Trials ........... 8
Number of Threads ........ 1
Head Tolerance ........... 0.005000 ft
```

2.4 MODEL PARAMETERIZATION

The sections below describe the model parameters used to simulate the existing Openlands project sites. Most of the acquired data were brought into GIS to populate the data fields and assign values to model parameters based on their spatial location.

2.4.1 Climatology

Vegetation changes during the wetland restoration process are expected to increase evapotranspiration (change in species and increased root depths). As mentioned above, regional data from the St. Charles Station are used for daily evaporation. A continuous time-series was created containing daily total potential evapotranspiration data from December 2011 through December 2015. To account for changes due to different vegetation, "crop coefficients" were used as outlined in the Food and Agriculture organization (FAO) Irrigation and Drainage Paper 56 (Allen et al., 1998). The crop coefficient method uses the Penman-Monteith evaporation equation to create a standard reference potential evapotranspiration value, which can then be scaled to a variety of different crop types by multiplying the value by the appropriate crop coefficient.

The single crop coefficient $K_{c\ mid}$ for specified vegetation types (Table 12 in Allen et al, 1998) was multiplied by the ISWS Illinois Climate Network daily potential evapotranspiration data time-series to account for the changing plant types during restoration activities. For Deer Grove East existing conditions, the evaporation time-series data was multiplied by a $K_{c\ mid}$ of 1.05 (Forage/Rye Grass hay), representing Eurasian Meadow Grass with a pre-restoration rooting depth of 24 inches. The Deer Grove East post-restoration model uses a $K_{c\ mid}$ multiplier of 1.15 (Average of Wetland Short Vegetation and Bulrushes) to represent Native Prairie vegetation that is forb dominated with an estimated rooting depth of 84 inches. Table 3 summarizes the crop coefficient information used for the Deer Grove East model simulations.

Table 3 Deer Grove East - Crop Coefficients Used

Model Scenario	Observed Vegetation	Representative Crop	Crop Coefficient ($K_{c\ mid}$)
Pre-Restoration	Eurasian Meadow Grass	Forage/Rye Grass hay	1.05
Post-Restoration	Native Prairie vegetation	Wetland Short Vegetation/Bulrushes	1.15

The Tinley Creek West site uses a weighted average crop coefficient based on the different types of crops/vegetation available as reported in Exhibit B of the Tinley Creek Wetlands 2014 Monitoring Report (Living Habitats 2015). Applying the mapping data to the sub-catchments spatially, an average pre-restoration crop coefficient of 1.03 was used for the Tinley Creek West model, while an average value of 1.08 was used for post-restoration conditions. Table 4 summarizes the crop coefficient information used for the Tinley Creek West model simulations.

Table 4 Tinley Creek West - Crop Coefficients Used

Model Scenario	Observed Vegetation	Crop Coefficient ($K_{c\ mid}$)
Pre-Restoration	Grass (avg.)	1.02
Pre-Restoration	Tall Fescue	0.90
Pre-Restoration	Reedcanary Grass	1.10
Pre-Restoration	Leafy Spurge	1.05
Pre-Restoration	Woods	1.05
Post-Restoration	Emergent Wetland	1.20
Post-Restoration	Sedge Meadow	1.15
Post-Restoration	Wet Prairie	1.10
Post-Restoration	Mesic Prairie	1.10
Post-Restoration	Native Prairie vegetation	1.05

2.4.2 Sub-catchment Parameterization

The sub-sections below describe how inputs were assigned for each sub-catchment for both the pre-restoration and post-project conditions. A majority of the inputs remained unchanged between the two scenarios. For example, the sub-catchment areas, imperviousness percentage, average slope percentage, and flow path lengths did not deviate between the two models because large scale grading or landuse changes did not take place. Additionally, the soil types remained consistent between pre- and post-restoration scenarios. General input differences between the two scenarios are noted below.

2.4.2.1 Rain Gage

Each sub-catchment was assigned the same rain gage containing the time-series in “volume” rain format entered from the USGS datasets. The time interval for the projects’ rain gage is specific to the data acquired.

2.4.2.2 Outlet

Sub-catchments were assigned an outlet based on the nearest routing location. For the Deer Grove East site, this typically meant the closest downstream wetland or surface drainage channel. Outlets for the Tinley Creek West site included downstream outfalls of the two main drainage channels and outfalls for individual drain-tiles that were labeled as leaving the site with an off-site outfall.

2.4.2.3 Acreage

Each of the sub-catchments within the study areas were delineated using existing topography. The geometry was calculated using the NAD83 Illinois East State Plane Coordinate System within ArcGIS. The Deer Grove East modeled area contains about 220 acres of watershed area divided into 33 sub-catchments with while the Tinley Creek West model covers about 1,260 acres broken into 26 sub-catchments.

2.4.2.4 Width and Average Slope

Multiple representative flow paths for each sub-catchment were measured in order to find an average flow path length at the Deer Grove East site. The average flow path length was divided into the sub-catchment acreage in order to calculate an average width for each sub-catchment. Multiple representative flow paths of each sub-catchment were also measured in order to find an average percent slope for each sub-catchment. Elevation changes were taken from the contours using existing survey data.

For the Tinley Creek site, width was determined by multiplying the longest flow path length for each sub-catchment by a skew factor, as outlined in the SWMM Reference Manual Volume I – Hydrology. The skew factor represents the ratio of approximate contributing drainage area on each side of the longest flow path. The average slope was calculated using GIS processing of DEM data.

2.4.2.5 Percent Impervious

Surfaces such as roads, sidewalks, parking lots, buildings and long-term standing water were measured within GIS to determine the impervious acreage. Standing water was estimated using aerial imagery and survey data. The total area was divided by the impervious area to determine the percent impervious value for each sub-catchment.

2.4.2.6 Surface Roughness

Manning's "n" values for overland flow over impervious parts of the sub-catchment were assigned a uniform value of 0.015. This is an average typical value for an impervious surface. Pervious surfaces were assigned an "n" value based on land types described in the Federal Highway Administration *Hydrology* report (FHWA-SA-96-067). At Deer Grove East, land described as short grass/prairie are given a value of 0.15 and forest with dense underbrush was given a value of 0.80.

Changes in vegetation types between the pre-restoration and post-restoration conditions will likely have impacts to the surface roughness and detention storage. Changes in vegetation result in changes to surface roughness; roughness typically increases from pre-restoration conditions as wetlands are restored and plant density increases. For the Deer Grove East model, areas where vegetation restoration activities take place were assigned a value of 0.24 in pre-restoration conditions and 0.40 in the post-project scenario.

The landuse areas were measured in GIS and values were assigned to each sub-catchment according to their spatial location. Table 5 summarizes the values used for surface roughness at the Deer Grove East site.

Table 5 Deer Grove East - Surface Roughness Values Used

Model Scenario	N-Impervious	N-Pervious Grass	N-Pervious Wetland	N-Pervious Forest
Pre-Restoration	0.015	0.15	0.24	0.80
Post-Restoration	0.015	0.15	0.40	0.80

The Tinley Creek West model used more precise values for the Manning's "n" value based on the vegetation information available (Living Habitats, 2015). Table 7 summarizes the values used for surface roughness within the Tinley Creek model for both pre- and post-restoration conditions. Between pre-restoration and post-project conditions at the Tinley Creek West site, surface roughness generally decreased based on changing part of the site's vegetation from woods

(2008 conditions) to wetland related species (Post-Project). The decreased Manning's "n" roughness values changed from 0.8 to approximately 0.2.

Table 6 Tinley Creek West - Surface Roughness Values Used

Pre-Restoration		Post-Restoration	
Vegetation	**Manning's "n"**	**Vegetation**	**Manning's "n"**
Grass (avg.)	0.2	Emergent Wetland	0.05
Tall Fescue	0.24	Sedge Meadow	0.15
Reedcanary Grass	0.2	Wet Prairie	0.2
Leafy Spurge	0.15	Mesic Prairie	0.2
Woods	0.8	Woods	0.8

2.4.2.7 Depression Storage

Typical depression storage values (ASCE – Design & Construction of Urban Stormwater Management Systems) were assigned to each sub-catchment. For the Deer Grove East site, impervious depression storage areas received a value of 0.05 inches, while pervious surfaces were assigned a value of 0.25 inches.

The Tinley Creek West site contrasts with the Deer Grove site as it does not contain deep depressional storage areas. Instead, it has large expanses of shallow surface storage. The surface storage volume was incorporated into the pervious depression storage parameter. Surface storage volumes were calculated from the DEM data and then normalized to a depth over the entire pervious area for each sub-catchment. Impervious depression storage was assumed to be 0.08 inches with 50% of the impervious area having no depressional storage.

2.4.2.8 Miscellaneous Parameters

Several parameters within the sub-catchments were set to their default values. These include the Zero-Impervious field (25%), Subarea Routing method (OUTLET), Percent Routed (100%), and Curb Length (0).

2.4.3 Infiltration Parameterization

Using SSURGO, a soil map and its associated data were imported into GIS. The soil characteristics were applied to each sub-catchment using the data's spatial location and an area-weighted methodology.

2.4.3.1 Surface Infiltration

The Modified Green-Ampt infiltration method was used for the analysis due to the known soil types from NRCS SSURGO data, and to maintain consistency between the surface and aquifer infiltration parameters. Parameters such as suction head and saturated hydraulic conductivity can be determined once general soil types are known by using the Green-Ampt parameters for different soil classes table (Table 4-7) (Rawls et al., 1983) within the SWMM Reference Manual – Volume I – Hydrology. The typical surface infiltration values for multiple soil types are shown in Figure 6.

Initial deficit values were taken from a table using values synthesized from the Handbook of Hydrology (D.R. Maidment 1993) and applied spatially as well. Table 7 summarizes the initial deficit values used for each type of soil class within the Deer Grove East site.

Figure 6 Surface Infiltration Parameters

Table 4-7 Green-Ampt parameters for different soil classes (Rawls et al., 1983)

(Numbers in parentheses are ± one standard deviation from the parameter value shown.)

Soil Class	Porosity, ϕ	Effective Porosity, ϕ_e*	Wetting Front Suction Head, ψ_s (in)	Saturated Hydraulic Conductivity, K_s (in/hr)
Sand	0.437 (0.374–0.500)	0.417 (0.354–0.480)	1.95 (0.38–9.98)	4.74
Loamy sand	0.437 (0.363–0.506)	0.401 (0.329–0.473)	2.41 (0.53–11.00)	1.18
Sandy loam	0.453 (0.351–0.555)	0.412 (0.283–0.541)	4.33 (1.05–17.90)	0.43
Loam	0.463 (0.375–0.551)	0.434 (0.334–0.534)	3.50 (0.52–23.38)	0.13
Silt loam	0.501 (0.420–0.582)	0.486 (0.394–0.578)	6.57 (1.15–37.56)	0.26
Sandy clay loam	0.398 (0.332–0.464)	0.330 (0.235–0.425)	8.60 (1.74–42.52)	0.06
Clay loam	0.464 (0.409–0.519)	0.309 (0.279–0.501)	8.22 (1.89–35.87)	0.04
Silty clay loam	0.471 (0.418–0.524)	0.432 (0.347–0.517)	10.75 (2.23–51.77)	0.04
Sandy clay	0.430 (0.370–0.490)	0.321 (0.207–0.435)	9.41 (1.61–55.20)	0.02
Silty clay	0.479 (0.425–0.533)	0.423 (0.334–0.512)	11.50 (2.41–54.88)	0.02
Clay	0.475 (0.427–0.523)	0.385 (0.269–0.501)	12.45 (2.52–61.61)	0.01

*Effective porosity is the difference between the porosity ϕ and the residual moisture content ϕ_r that remains after a saturated soil is allowed to drain thoroughly.

Table 7 Initial Deficit Values Used

Soil Class	Initial Deficit
Sand	0.346
Loamy Sand	0.312
Sandy Loam	0.246
Loam	0.193
Silt Loam	0.171
Sandy Clay Loam	0.143
Clay Loam	0.146
Silty Clay Loam	0.105
Sandy Clay	0.091
Silty Clay	0.092
Clay	0.079

2.4.3.2 Sub-Surface Aquifer

Parameters such as porosity, wilting point, and field capacity can also be found once general soil types are known by using the SWMM Hydrology Reference Manual (Table 5-3). The typical values for multiple soil types are shown in Figure 7. These soil characteristics are used within the "Aquifer Editor". Because multiple sub-catchments can utilize the same aquifer, inputs were averaged based on the sub-catchment data using the specified aquifer.

Figure 7 Sub-Surface Soil Parameters

Table 5-3 Average moisture limits and saturated hydraulic conductivity for different soil types (Rawls et al., 1983)

Soil Type	Porosity (ft^3/ft^3)	Field Capacity (ft^3/ft^3)	Wilting Point (ft^3/ft^3)	Saturated Hydraulic Conductivity (in/hr)
Sand	0.437	0.062	0.024	4.74
Loamy sand	0.437	0.105	0.047	1.18
Sandy loam	0.453	0.190	0.085	0.43
Loam	0.463	0.232	0.116	0.13
Silt loam	0.501	0.284	0.135	0.26
Sandy clay loam	0.398	0.244	0.136	0.06
Clay loam	0.464	0.310	0.187	0.04
Silty clay loam	0.471	0.342	0.210	0.04
Sandy clay	0.430	0.321	0.221	0.02
Silty clay	0.479	0.371	0.251	0.02
Clay	0.475	0.378	0.265	0.01

The conductivity slope parameter was derived from Table 5-9 of the SWMM Hydrology Reference Manual. Figure 8 shows typical values to use (HCO) for the conductivity slope. The HCO values were adjusted for calibration purposes using observed data.

Figure 8 Sub-Surface Soil Parameters – Conductivity Slope

Table 5-9 Estimated HCO for different soil types

Soil Type	Percent Sand	Percent Clay	HCO
Sand	92	5	48
Loamy sand	82	6	44
Sandy loam	65	10	40
Loam	42	18	35
Silt loam	20	20	27
Sandy clay loam	60	28	53
Clay loam	33	34	45
Silty clay loam	10	34	34
Sandy clay	52	42	61
Silty clay	7	47	43
Clay	30	50	57

Additional aquifer parameters adjusted during the calibration phase include the tension slope, upper evaporation factor, lower ground water loss rate, and unsaturated zone moisture fraction. Theses parameters were initially set to their default values and adjusted as needed to refine the shape of the ground water elevation to better calibrate the model to observed water levels.

Along with the expected pervious roughness “n-value”, the vegetation data helps to derive a species root depth which offers practical information for modeling the “Lower Evaporation Depth”. The lower evaporation depth parameter was differentiated between the pre-restoration and post-project conditions due to the expected change in vegetation root depths. The Deer Grove East pre-restoration conditions were given a lower evaporation depth of 2 feet due to the expected shallow roots from Eurasian Meadow Grass. An average root depth of 2.4 feet was assigned for the areas within the Tinley Creek West site with grass cover. An area weighted average root depth of 3.3 feet was used for the pre-project Tinley Creek West site based on all the coverage types expected (including trees). The post-project Native Prairie vegetation used on both project sites generally contains species with an expected increased root depth. This change was applied to the lower evaporation depth parameter. Values were adjusted during the calibration phase, but typical values modeled range between 4 and 7 feet.

2.4.4 Sub-Surface Tile Network

Sub-surface flow is simulated using the “Groundwater Flow Editor” in SWMM. As mentioned above, the team calculated coefficients from Hooghoudt’s Equation in order to simulate the effects of the tile drainage because there is not a direct input for creating drain tiles within SWMM. The method reduces a series of simultaneous equations to simple functions of drain spacing, drain diameter, and depth to the impermeable soil layer. Hooghoudt's Equation for tile drainage is found in the SWMM Hydrology Manual (Equation 5-38).

Within the "Groundwater Flow Editor", there is an input for the node that receives groundwater flow from the aquifer. Typically, the downstream tile node was used. For post-restoration conditions where the drain tile was removed, abandoned or plugged, the team zeroed out the Hooghoudt's Method coefficients and changed the receiving node to one that has an invert at the ground surface. This methodology eliminates the transport of groundwater flow while accounting for the groundwater storage and the interflow of groundwater and surface drainage.

The Bottom Elevation of the aquifer was determined through the restrictive layer data within the soil characteristics and from observed monitoring data at each well. The observed data also provides an indication to the approximate starting point for a water table elevation used at the beginning of a simulation.

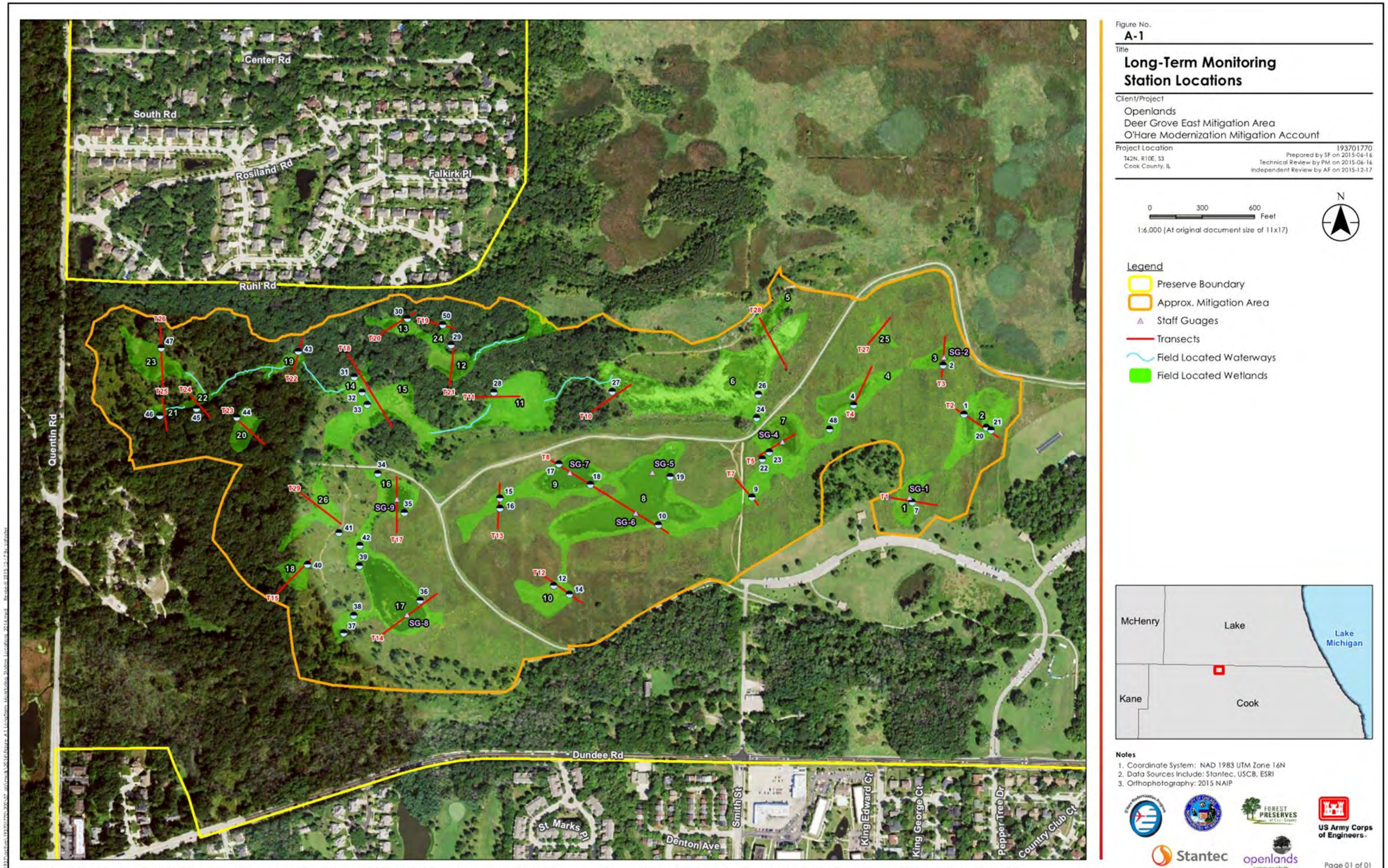
2.5 MODEL CALIBRATION

Model calibration was performed using the specified meteorological data, simulation times and observed data and results.

Stantec utilized information collected from the restoration areas to calibrate the model. The figure titled "Long-Term Monitoring Station Locations for the Openlands Deer Grove East Mitigation Area" shows well locations where data are available for several time periods at the Openlands project sites. Figure 9 shows the monitoring station location map for Deer Grove East. Data was recorded from 45-50 wells from 2010-2015 during the growing season at the Deer Grove East site. Most wells have data at 2-hour increments and daily averages. The information at each well provided the team existing data to calibrate the modeled groundwater against. Since a majority of the restoration activities have already occurred, the 2014 and 2015 rainfall datasets were used to calibrate the post-restoration conditions model.

Modeled aquifer parameters were adjusted during the calibration phase to better match the groundwater elevations observed within the field collected data. These parameters include the conductivity slope, tension slope, upper evaporation factor, lower ground water loss rate, and unsaturated zone moisture fraction. Theses parameters were initially set to their default values and adjusted as needed to refine the shape of the ground water elevation.

Figure 9 Long-Term Monitoring Station Locations – Deer Grove East



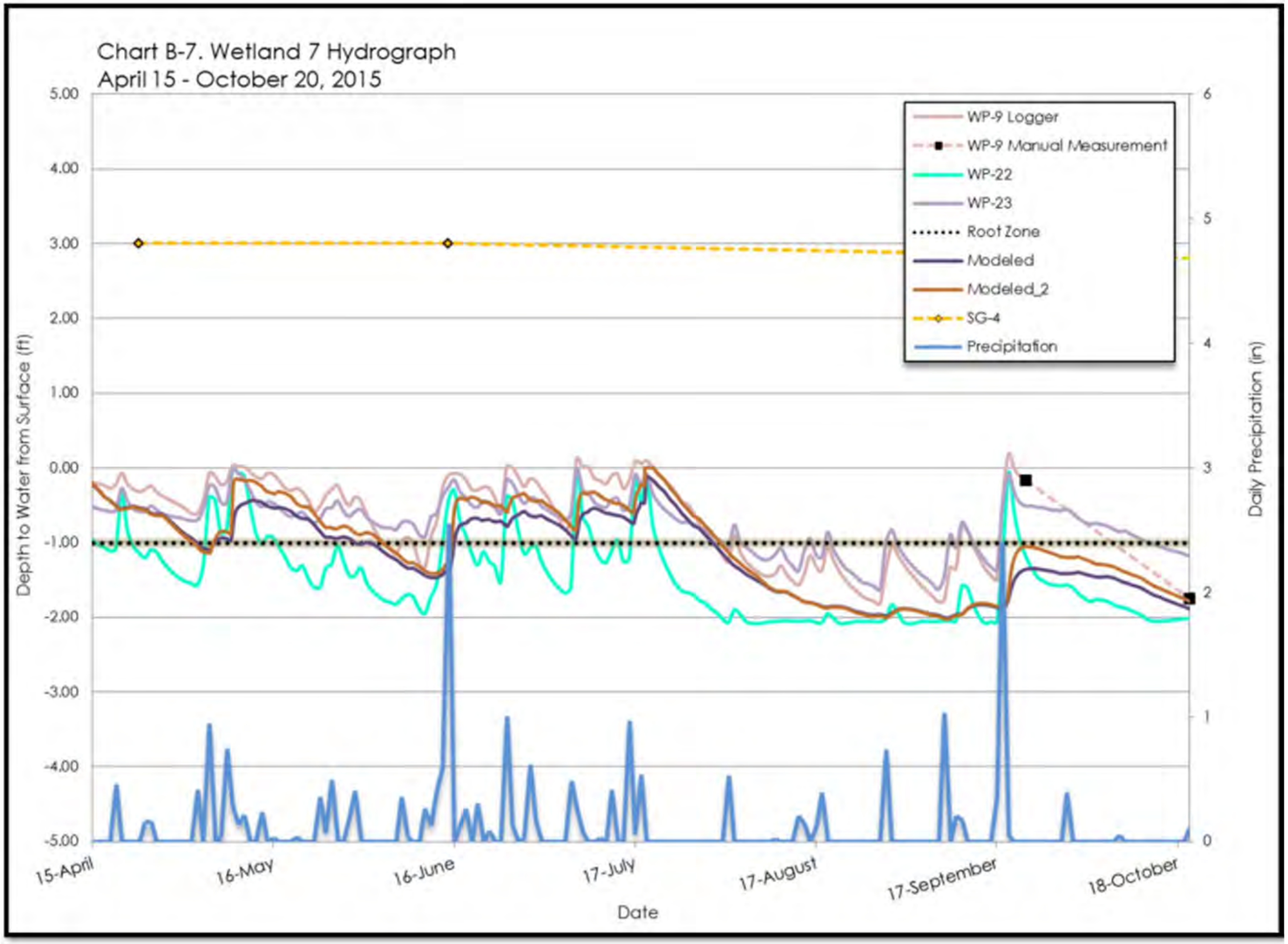
2.5.1 Calibration Results

The results of the calibration were visually inspected using information derived from the observed well logger data and the model's continuous simulation results (depth of groundwater from the surface). Calibration graphs from the Deer Grove East site are contained within Appendix C. Calibration graphs from the Tinley Creek West site are contained within Appendix D. The precipitation data shown on the graphs represent the local daily observed rainfall amount on the project site and does not represent the USGS rainfall data used in the analysis.

Several wetlands contained multiple monitoring wells with each well producing slightly different observed groundwater depths at the Deer Grove East site; however, the modeled results are simplified to one groundwater elevation time-series per wetland from the sub-catchment containing the wetland. In these cases, the modeled results typically were aligned between the observed well depths. Figure 10 shows an example graph with multiple observed wells. In this graph, the modeled results fall between the multiple wells at the location of Wetland 7.

A significant majority of the calibration graphs show the models reasonably predict (within 6-12 inches) a match to the observed data for most of the continuous simulations for both 2014 and 2015. The modeled results also typically follow the general trend of peaks and recessions of the observed well data. Figure 10 shows the modeled data results are within 6-12 inches of the wells' observed data.

Figure 10 Example Calibration Graph



2.5.2 Calibration Discussion

The SWMM models used the groundwater option, allowing the surface and sub-surface layers to exchange flow via infiltration and groundwater interaction. The Openlands sites had a substantial amount of groundwater data to calibrate against. Without the observed data, uncertainty would remain high for the groundwater parameter inputs. The number of wells and duration of observed data provided meaningful information to use in updating the models.

The observed well data were useful for determining the varying levels of groundwater at key points in the hydrologic and hydraulic system. The observed well data at multiple locations increased certainty for specific model parameters like water table elevation, lower evaporation depth, and groundwater loss rate. These parameters are integral for sub-surface modeling and impacted the results in a positive and meaningful way.

The modeled results reasonably match the observed data for a majority of the simulation events. The results of the sub-surface calibration can be considered successful in that the data provided helpful information in order to increase the certainty in the models.

For future projects, monitoring data of pre-restoration conditions would assist in isolating the differences in results and refining the assumed parameter inputs. Additional data such as surface flow monitoring data would have also been useful to calibrate sub-catchment parameters (Manning's "n" values, infiltration parameters, etc.) to increase the certainty in the subsequent modeled surface runoff results. Monitoring discharge pipes would assist in tracking the overall volume leaving the site via surface and drain tile flow.

3.0 TOOL RESULTS

Stantec and its team members applied the successfully calibrated modeling tool to analyze and quantify the volume and flow through the existing Openlands project sites for both pre-restoration and post-project conditions with simulated runs encompassing the duration of the growing season (2014 and 2015).

Model results were compared between the pre- and post-restoration scenarios using the status report information within the model. Information related to the water budget and hydrologic cycle such as total precipitation, evaporation and infiltration loss, surface runoff, initial and final storage, upper and lower zone ET, deep percolation and groundwater flows were some of the summary outputs reviewed. Table 8 and Table 9 provide a cumulative summary of the water budget results at each site for both the 2014 and 2015 model simulations.

Figure 11 through Figure 18 provide an illustrative summary of the incremental model results for both sites on a monthly basis.

Table 8 Deer Grove East – Model Simulation Results Summary

	2014			2015		
	Pre-Restoration	Post-Project	Percent Change	Pre-Restoration	Post-Project	Percent Change
	Sub-catchment Results (Inches)					
Precipitation	27.0	27.0	0%	28.7	28.7	0%
Surface Evaporation	1.9	1.2	-36%	2.2	1.0	-56%
Infiltration (to Groundwater)	20.0	21.7	9%	22.7	24.7	9%
Surface Runoff	5.3	4.2	-20%	3.9	3.2	-19%
	Groundwater Results (Inches)					
Total Infiltration	19.5	21.4	10%	22.2	24.4	10%
Upper Zone ET	1.6	1.9	19%	1.7	2.2	24%
Lower Zone ET	12.6	20.9	67%	13.2	22.8	72%
Groundwater Loss	2.5	2.5	-1%	2.5	2.4	-4%
Tile Drainage	6.7	0.1	-99%	7.0	0.0	-99%

Table 9 Tinley Creek West – Model Simulation Results Summary

	2014			2015		
	Pre-Restoration	**Post-Project**	**Percent Change**	**Pre-Restoration**	**Post-Project**	**Percent Change**
	Sub-catchment Results (Inches)					
Precipitation	31.8	31.8	0%	29.5	29.5	0%
Surface Evaporation	2.4	5.0	112%	1.6	3.5	112%
Infiltration (to Groundwater)	26.9	22.3	-17%	26.2	24.0	-8%
Surface Runoff	2.7	4.6	75%	1.8	2.1	16%
	Groundwater Results (Inches)					
Total Infiltration	26.4	20.0	-25%	25.7	22.7	-12%
Upper Zone ET	0.0	0.0	0%	0.0	0.0	0%
Lower Zone ET	13.8	17.4	27%	15.3	21.0	37%
Groundwater Loss	4.2	4.5	5%	4.1	4.3	4%
Tile Drainage	10.5	0.0	-100%	9.1	0.0	-100%

Figure 11 Deer Grove East – Pre-Restoration Model Results (2014 Data)

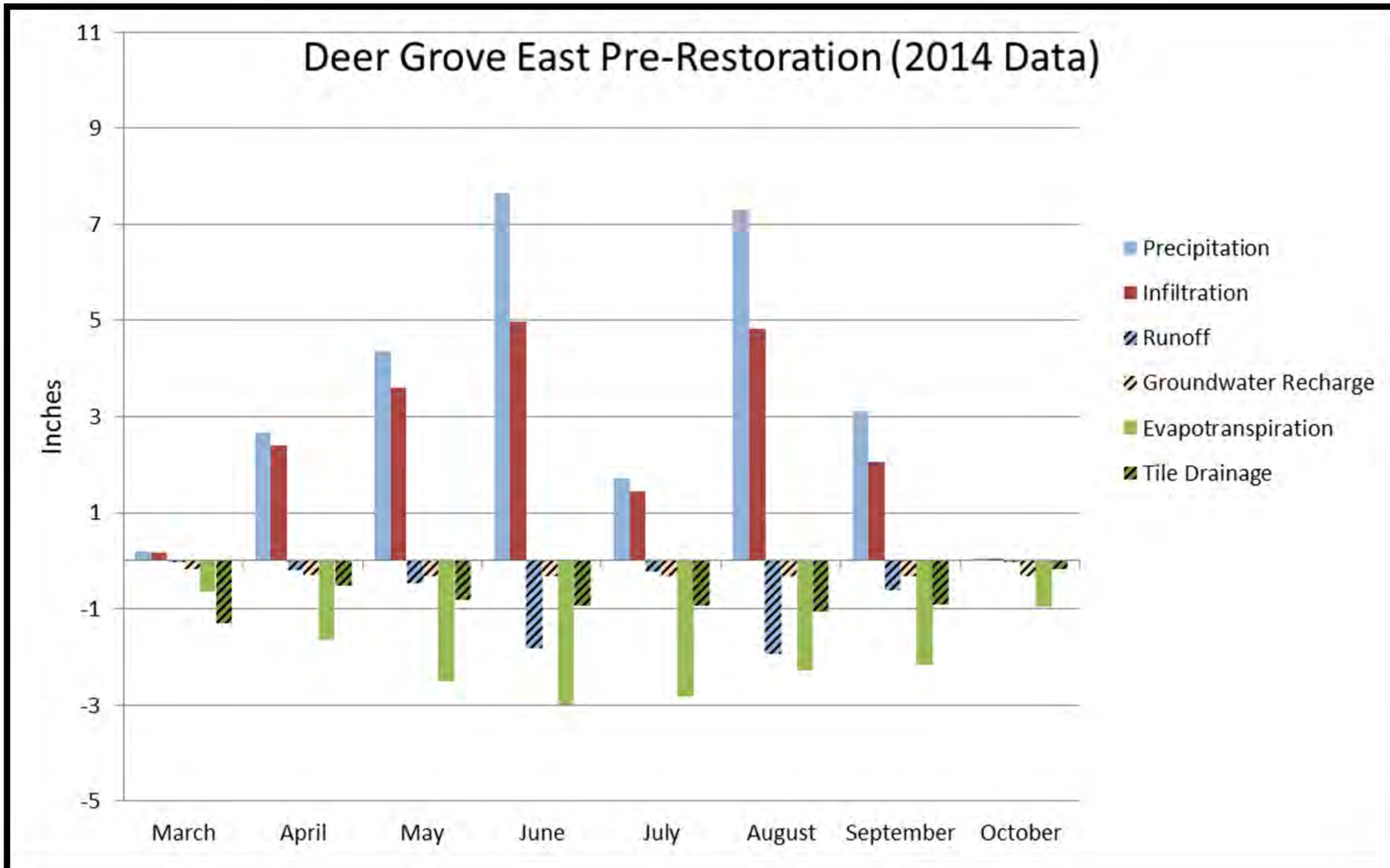


Figure 12 Deer Grove East – Post-Restoration Model Results (2014 Data)

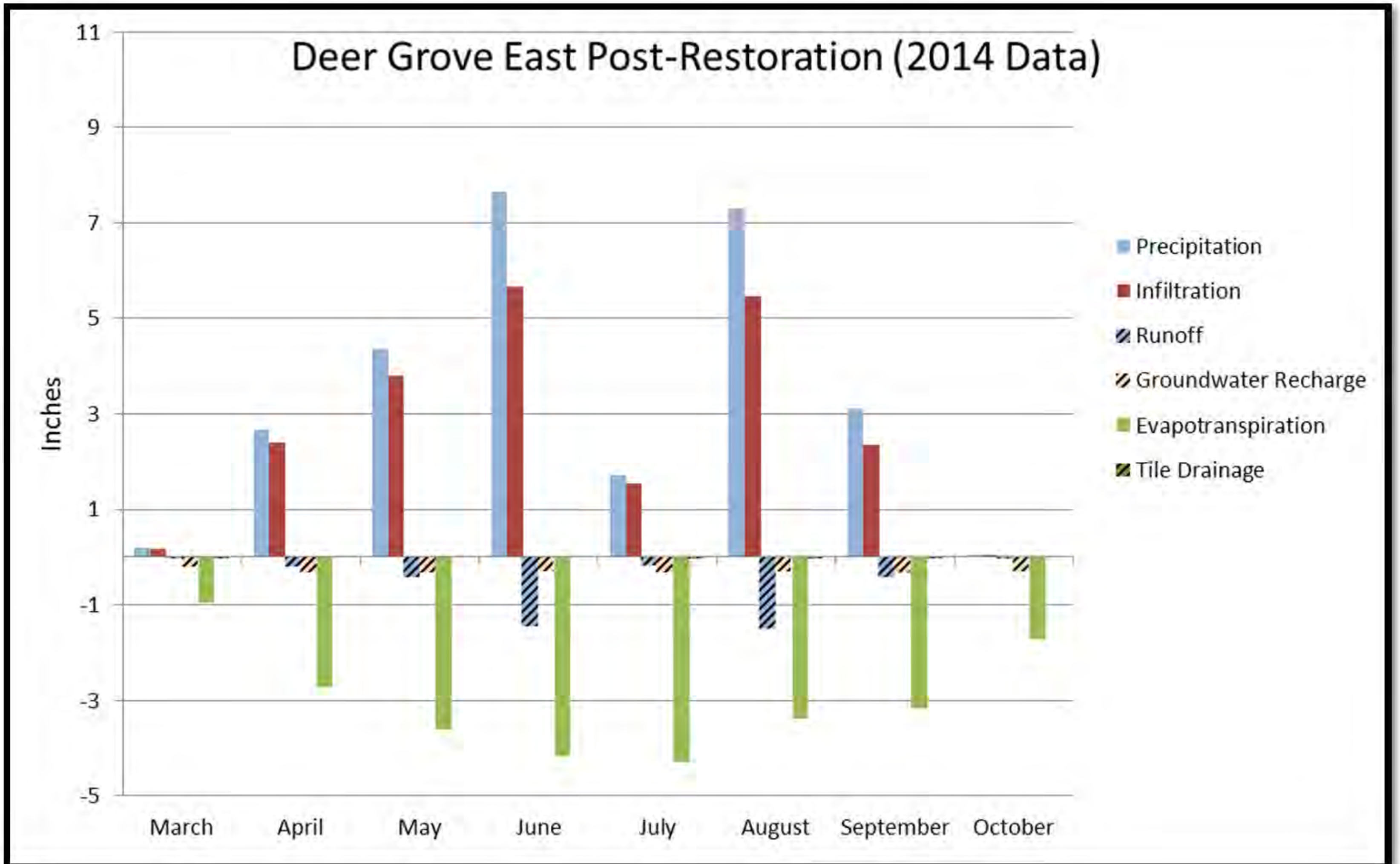


Figure 13 Deer Grove East – Pre-Restoration Model Results (2015 Data)

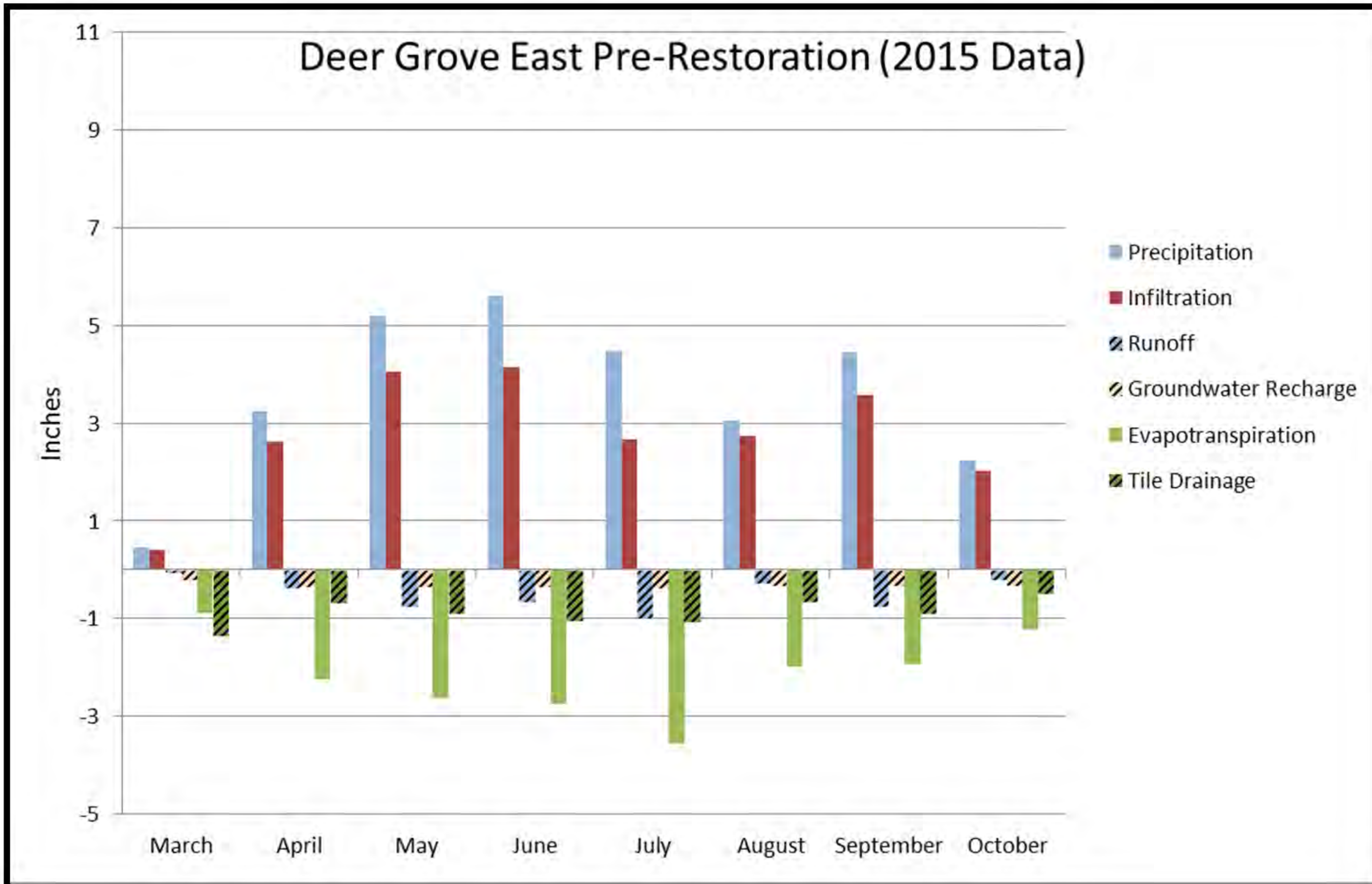


Figure 14 Deer Grove East – Post-Restoration Model Results (2015 Data)

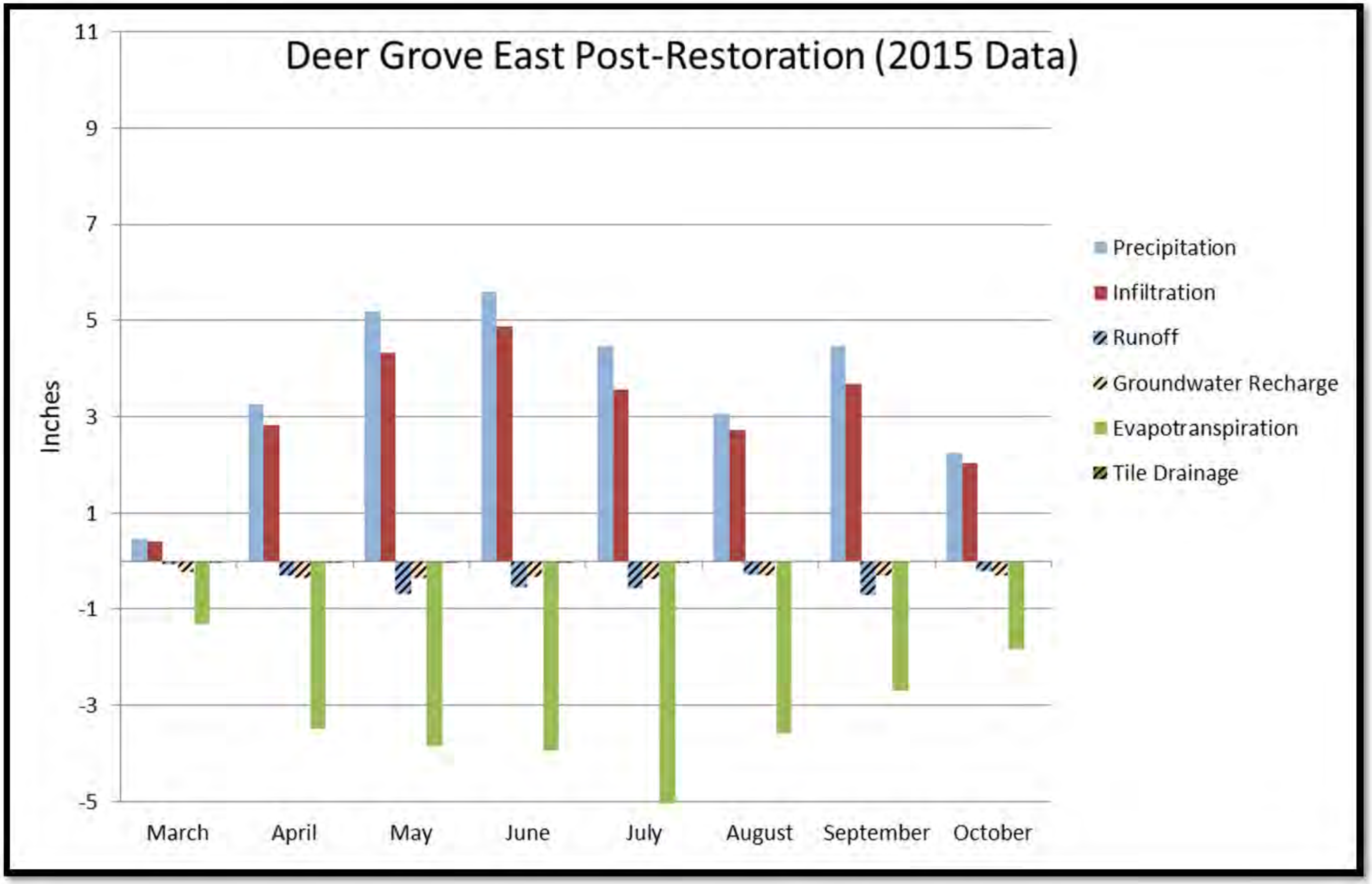


Figure 15 Tinley Creek West – Pre-Restoration Model Results (2014 Data)

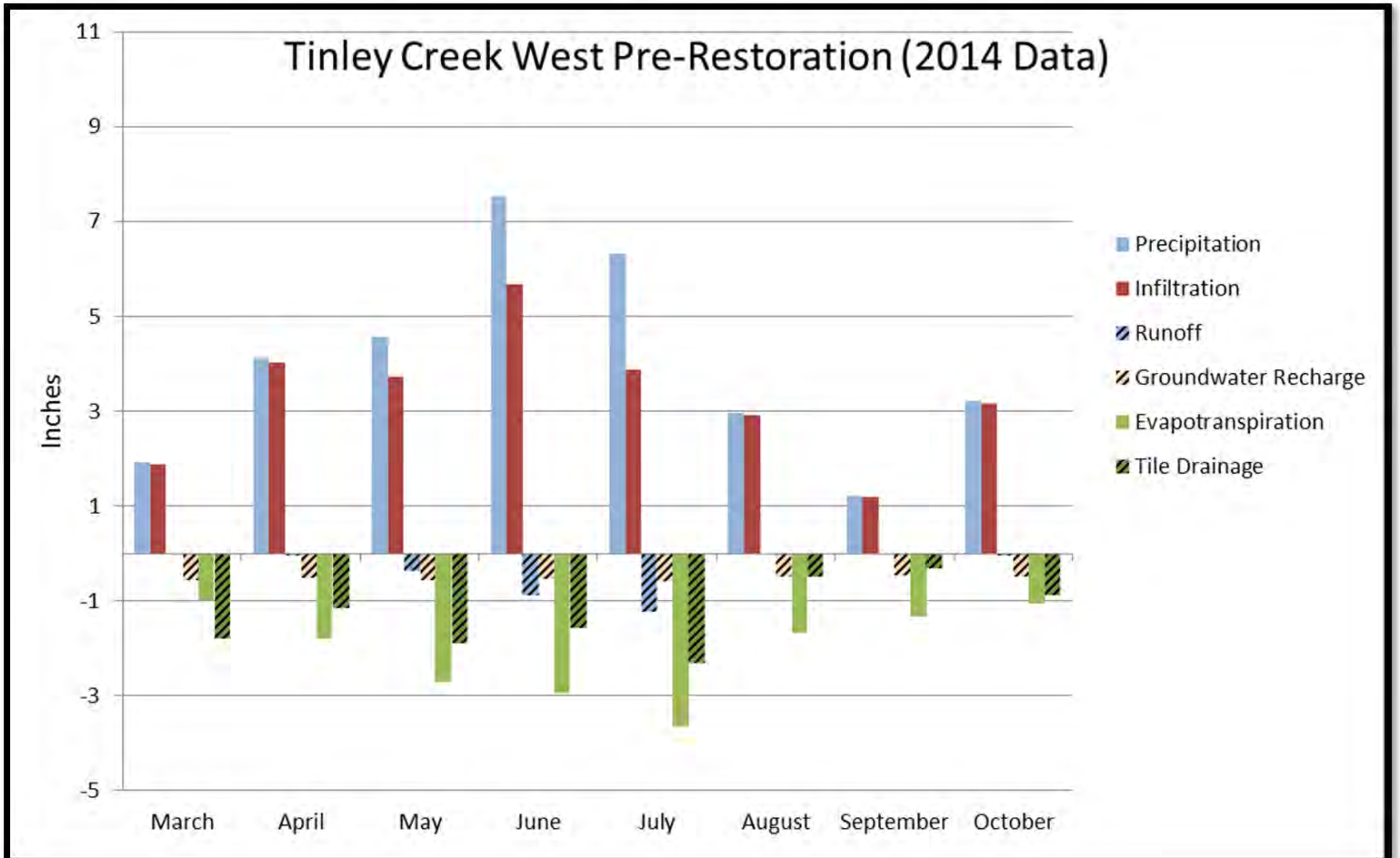


Figure 16 Tinley Creek West – Post-Restoration Model Results (2014 Data)

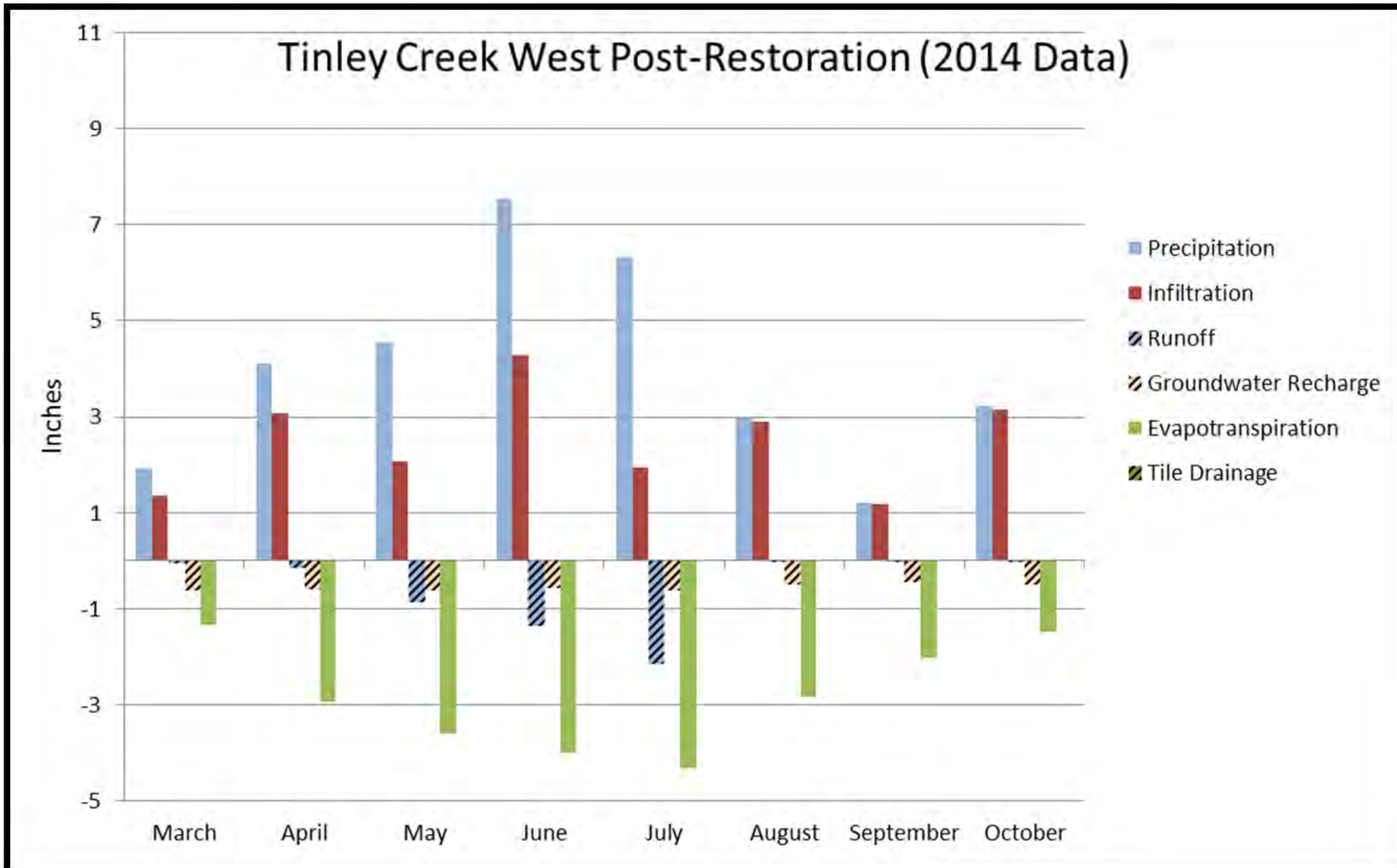


Figure 17 Tinley Creek West – Pre-Restoration Model Results (2015 Data)

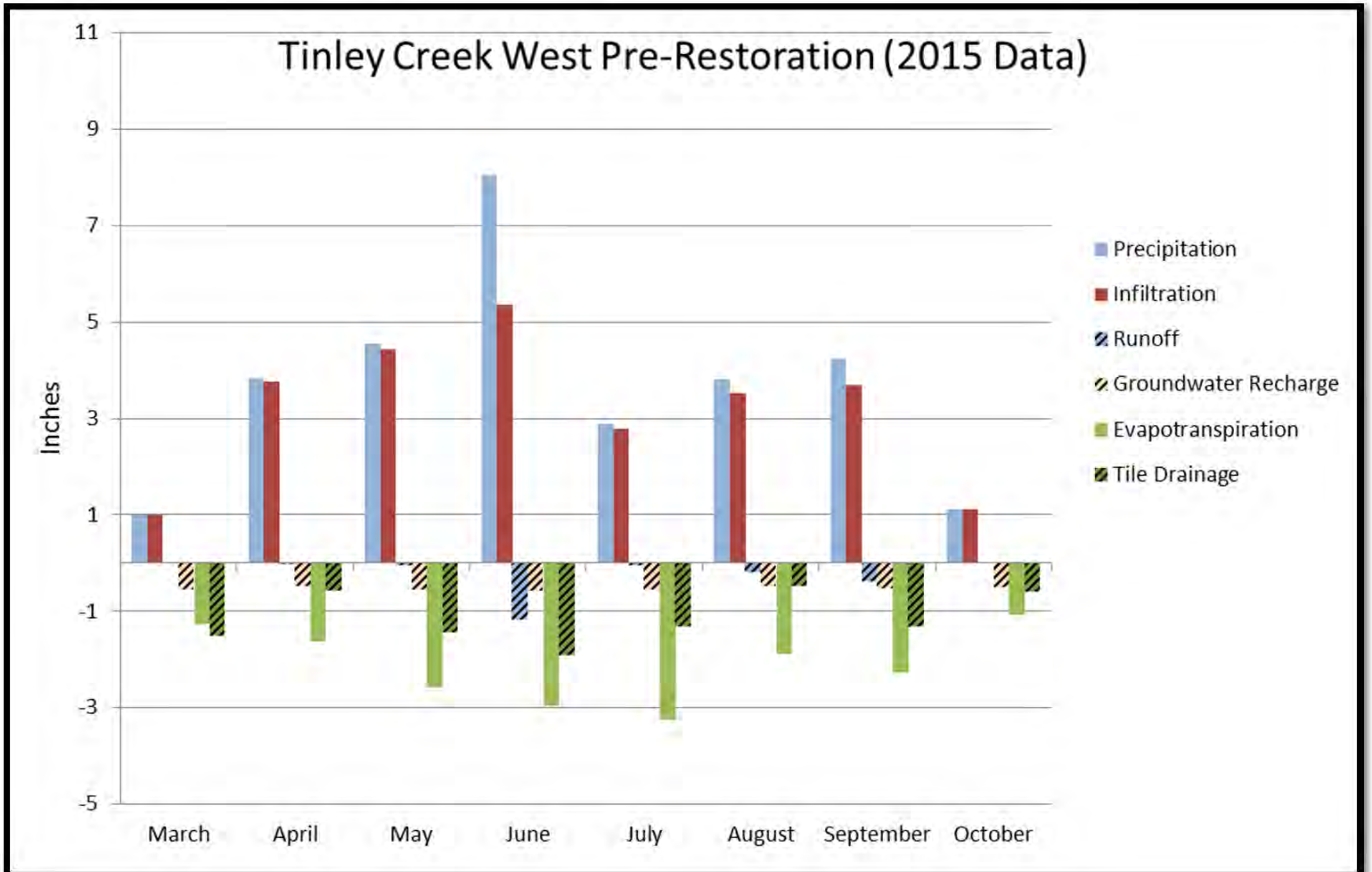
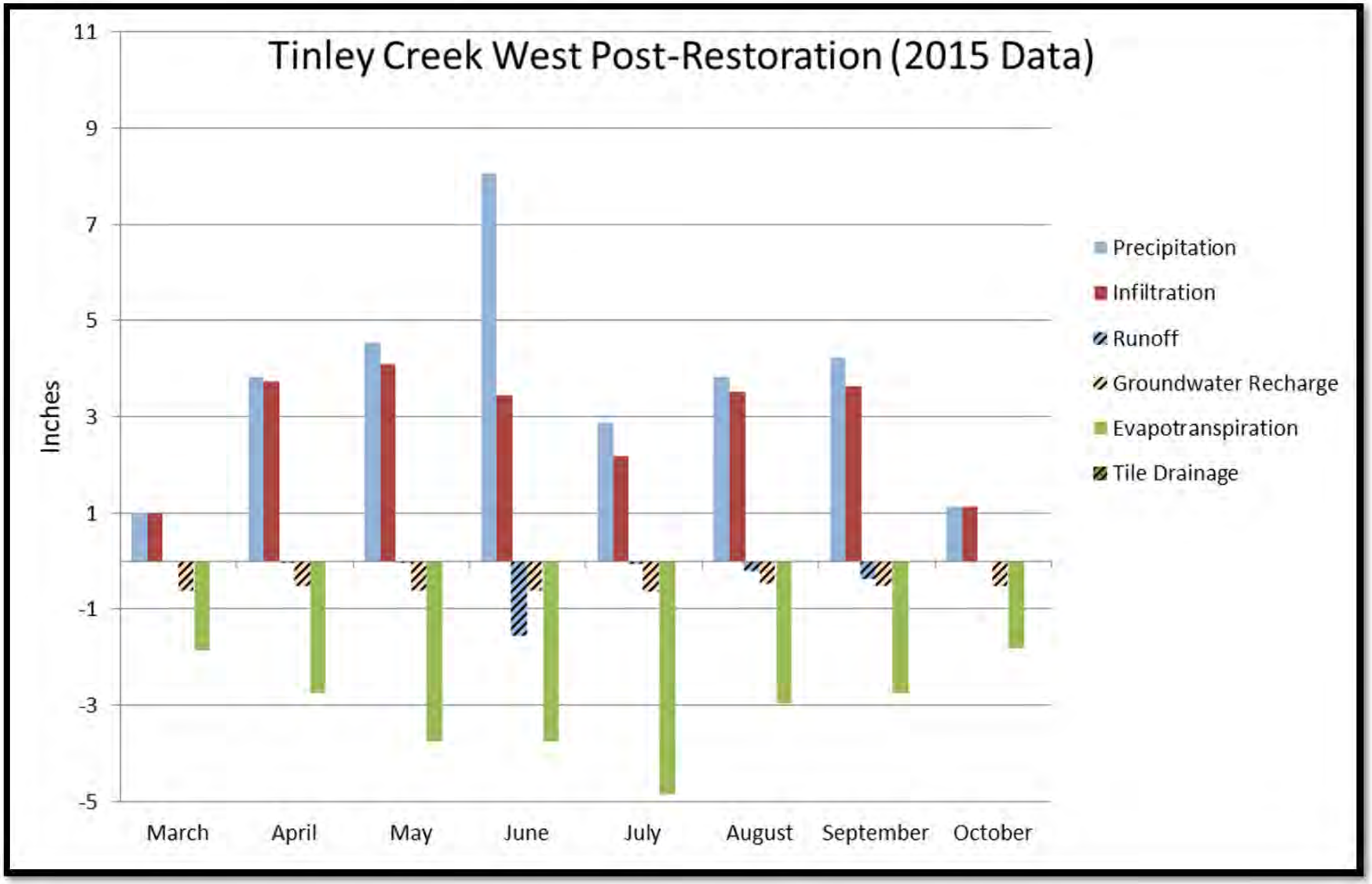


Figure 18 Tinley Creek West – Post-Restoration Model Results (2015 Data)



3.1 MODEL DISCUSSION

Climatology was expected to have contributed significantly to the hydrologic cycle during the growing season time period given the change in plant community involved in ecosystem restoration; that modification was expected to change both evaporation (change in surface runoff) and evapotranspiration (change in species and increased root depths). The tool results confirm these anticipated hydrologic effects of landscape scale ecosystem restoration, but also provide other insight into other hydrologic and hydraulic components of the restoration.

Despite the increase in evaporation crop coefficients, the surface evaporation results generally trended in the same direction as at the volume of surface runoff. Table 10 shows that at the Deer Grove East site, surface evaporation decreased between the pre-restoration and post-project models for both 2014 and 2015 despite the slight increase in surface storage volume and an increased crop coefficient. Surface runoff decreased by 20% in the Deer Grove East models, therefore, there was less flow available to evaporate. On the other hand, Table 11 shows that surface evaporation increased at the Tinley Creek West site in a similar manner as the increased surface runoff volume.

With a decrease in lateral outflow from the drain tile network and in increase in root depths, the models showed significant increases to lower zone evapotranspiration (ET) losses. In the Deer Grove East models, 54% of the pre-restoration groundwater flow went to lower zone evapotranspiration, while 83% contributed to the lower zone ET post-project. Lower zone ET increased in a similar magnitude at the Tinley Creek site; a 65% increase in 2014 and a 55% increase in 2015. Additionally, removal of portions of the drain tile within the post-restoration Deer Grove East models decreased the groundwater lateral outflow from 29% of groundwater flow to 0% with a 100% reduction at Tinley Creek West as well.

Table 10 Deer Grove East – Results Summary (As Percentages)

	2014			2015		
	Pre-Restoration	Post-Project	Percent Change	Pre-Restoration	Post-Project	Percent Change
	Sub-catchment Data (As a percentage of Precipitation)					
Evaporation	7%	4%	-36%	8%	3%	-56%
Runoff	20%	16%	-20%	14%	11%	-19%
Infiltration	74%	80%	9%	79%	86%	9%
	Infiltration Data (As a percentage of Groundwater Movement)					
(Upper Zone ET)	7%	7%	7%	7%	8%	11%
(Lower Zone ET)	54%	83%	53%	54%	83%	54%
(GW Recharge)	11%	10%	-12%	10%	9%	-14%
(Lateral Outflow)	29%	0%	-99%	29%	0%	-99%

Table 11 Tinley Creek West – Results Summary (As Percentages)

	2014			2015		
	Pre-Restoration	Post-Project	Percent Change	Pre-Restoration	Post-Project	Percent Change
	Sub-catchment Data (As a percentage of Precipitation)					
Evaporation	7%	16%	112%	6%	12%	112%
Runoff	8%	15%	75%	6%	7%	16%
Infiltration	85%	70%	-17%	89%	81%	-8%
	Infiltration Data (As a percentage of Groundwater Movement)					
(Upper Zone ET)	0%	0%	0%	0%	0%	0%
(Lower Zone ET)	48%	80%	65%	54%	83%	55%
(GW Recharge)	15%	20%	37%	15%	17%	17%
(Lateral Outflow)	37%	0%	-100%	32%	0%	-100%

Changes in modeled surface runoff and infiltration to groundwater varied between the Deer Grove East and Tinley Creek West project models. Overall, the Deer Grove East post-restoration model observed a decrease in local surface runoff and an increase in infiltration, while the Tinley Creek model's local surface runoff increased and the infiltration to groundwater decreased. The differing model results between the two sites are likely due to the differences in vegetation changes and contrasting topographic nature observed.

Between pre-restoration and post-project conditions at the Deer Grove East site, surface roughness increased based on changing the vegetation from brush to a thicker wetland species. The increased Manning's "n" roughness values directly impacted the local surface runoff volume within the Deer Grove East site. Model results show surface runoff decreased internally on the site by 20 acre-feet, or 6.5 million gallons during the 2014 growing season and by almost 14 acre-feet, or 4.5 million gallons, in 2015 at Deer Grove East. Table 12 below shows these results. According to the Illinois State Water Survey, the statewide precipitation normal for Illinois is 29.75 inches for the months of March through October. The rain data at Deer Grove East shows 27.03 inches of rainfall in 2014 and 28.72 inches of rainfall in 2015. The monthly incremental rainfall values indicate both these periods generally produce typical monthly rainfall values observed in Illinois.

Accounting for all the aspects of the hydrologic water budget and the removal of drain tile, discharge volumes of flow leaving the site is reduced by approximately 40 million gallons of water for both 2014 and 2015 model runs combined. Table 13 shows the reduction in site volume discharge leaving the Deer Grove East model pre- and post-restoration. The decrease in localized surface runoff volumes also corresponded to the decrease in rate/timing of storm water release from the Deer Grove East modeled areas between pre- and post-project conditions.

Table 12 Deer Grove East – Internal Surface Runoff Summary

Surface Runoff – Deer Grove East	
Scenario	**Volume (acre-feet)**
2014 Pre-Restoration	98.3
2014-Post-Project	78.3
2015 Pre-Restoration	72.6
2015 Post-Project	58.7

Table 13 Deer Grove East - Modeled Discharge Volumes Leaving Site

Site Discharge Volumes – Deer Grove East	
Scenario	**Volume (MG)**
2014 Pre-Restoration	21.5
2014-Post-Project	1.7
2015 Pre-Restoration	20.3
2015 Post-Project	0.7

Between pre-restoration and post-project conditions at the Tinley Creek West site, overall surface roughness decreased based on changing the vegetation from areas with woods (2008 conditions) to wetland related species (Post-Project). The decreased Manning's "n" roughness values in these formally wooded areas (from 0.8 to approximately 0.2) directly impacted the results and increased surface runoff volume.

The surface water runoff generated locally within the Tinley Creek West site increased within the hydrologic model when surface roughness decreased. Even though local surface runoff volume increased over the simulated period at Tinley Creek West, a decrease in drain tile outflow volume and an increase in evaporation and evapotranspiration quickly make up the difference in terms of discharge volume leaving the site. For instance, Table 9 shows that during 2014 the post-project model produces an increase in surface runoff of 1.9 inches (distributed across the watershed); however, surface evaporation and lower zone ET combine to decrease the water budget by 6.2 inches. Additionally, 10.5 inches of tile drainage no longer directly discharges from the site. The increase in local surface runoff at Tinley Creek West may lead to increased peak flow rates leaving the site during larger storm events (higher volume and intensity), and events that occur during times with wetter antecedent moisture conditions. However, model results also show that the total volume of water leaving the site that must be controlled throughout the year was reduced in post-project conditions.

Despite the increase in internal surface runoff, analysis of Tinley Creek's modeled outfalls locations indicate that the total volume of water leaving the site throughout the year is reduced due to the hydrologic and hydraulic changes associated with the restoration projects. The overall reduction in site discharge volume is due to increased evapotranspiration (from increased root depths) and a decrease in outflow from drain tiles. Accounting for all the aspects of the hydrologic water budget and the removal of drain tile, discharge volumes of flow leaving the site is reduced by approximately 181 million gallons of water for both 2014 and 2015 model runs combined. Table 14 shows the reduction in site volume discharge leaving the Tinley Creek West restoration site.

Table 14 Tinley Creek West – Modeled Discharge Volumes Leaving Site

Site Discharge Volumes – Tinley Creek West	
Scenario	**Volume (MG)**
2014 Pre-Restoration	219.7
2014-Post-Project	147.5
2015 Pre-Restoration	179.5
2015 Post-Project	70.2

3.2 CONCLUSIONS

A successful technical tool has been constructed and calibrated for the two Openlands restoration sites, Deer Grove East and Tinley Creek West, using commonly available data. The tool developed for this project is a viable means of quantifying the positive hydrologic changes resulting from landscape scale ecosystem restoration; these important environmental projects do have an appreciable effect on hydrology such as increased evapotranspiration and decreased discharge volumes of flow leaving the restoration sites. The reduction in storm water volume discharging from the restoration sites means that more water is being retained on-site where it is either evaporated, infiltrated or maintained as surface storage. Future modeling tools may be developed for additional restoration sites using the SWMM software package and data sets such as aerial imagery, site topography, soil, precipitation and evaporation data, and sub-surface hydraulic information (sizes, shapes, inverts, etc.). Model results can then be calibrated using available observed monitoring data.

An increase in the lower zone evapotranspiration loss is one of the most notable results of the modeling. Localized drain tile removal resulted in an increase in groundwater levels. Increased root depths of post-restoration vegetation allowed more shallow groundwater to be absorbed in the lower evapotranspiration zones.

Analysis of the Deer Grove East and Tinley Creek West Wetlands projects indicated that surface evaporation and infiltration to groundwater closely corresponds to internal site surface runoff volume, which is closely related to the landuse and its specified surface roughness values. As the surface roughness of a landuse increases, the infiltration to groundwater generally increases and the surface runoff volume within the site typically decreases, which in turn, decreases the available water for surface evaporation.

The results of the two test case models show the hydrologic effects of restoration are expected to be a site-specific balance of drain tile removal and a change in vegetation. From a surface runoff perspective, the Tinley Creek West model results show that in the removal of second-growth trees and conversion to grasslands, some more intense rainfall events will naturally generate more on-site surface runoff and depending on proximity to overall site exit points, may actually increase offsite surface outflow for particular storms. However, for small and more frequent rainfalls this was not typically observed. On an annual basis, reductions in outflow volume from both restoration sites were significant. If clearing trees is part of the restoration, adequate surface water control may be included as part of the project in the form of creating closed depressions and defined, stabilized outflow points to account for the increased peak flows during rainfall events with high volumes and intensities.

Overall, both models indicate that the total volume of water leaving the site throughout the year is reduced due to the hydrologic and hydraulic changes associated with the restoration projects. Future restoration projects like the ones at Deer Grove East and Tinley Creek West will likely experience similar hydrologic benefits such as increased evapotranspiration and decreased discharge volumes of flow leaving the restoration sites. Application of a tool similar to the models developed for Deer Grove East and Tinley Creek West could assist in predictive scenarios for future restoration sites by updating the hydrologic and hydraulic model components such as vegetation and drain tile modification.

The observed calibration data proved to be a valuable tool in quantifying hydrologic impacts to the sub-surface layer. For future projects, monitoring data of pre-restoration conditions would assist in isolating the differences in results and refining the assumed parameter inputs. Additionally, monitoring surface flows would allow for the calibration of sub-catchment parameters to increase the certainty in surface runoff. Monitoring discharge pipes would assist in tracking the overall volume leaving the site via surface and drain tile flow.

4.0 REFERENCES

Allen, R., Pereira, L., Raes, D., and Smith, M. (1998) Crop evapotranspiration – Guidelines for computing crop water requirements FAO – Food and Agriculture Organization of the United Nations. Rome, Italy.

ASCE,(1992), *Design & Construction of Urban Stormwater Management Systems*, New York, NY.

Huddleston McBride Professional Mapping Services, (2010), *Existing Drain Tile Investigation Modification and Abandonment Plan – Deer Grove East Restoration Area*, Prepared for Openlands and the Forest Preserve District of Cook County, Illinois, Rochelle, IL.

Living Habitats, (2015), *Tinley Creek Wetlands OMMA Project 2014 Monitoring Report*, Prepared for Openlands Land Preservation, Chicago, IL.

McCuen, R. et al. (1996), *Hydrology*, FHWA-SA-96-067, Federal Highway Administration, Washington, DC

Rawls, W.J. et al., (1983). *J. Hyd. Engr*., 109:1316.

Rossman, L. 2015. Storm Water Management Model Reference Manual Volume I – Hydrology. EPA-600-R-15-162. USEPA National Risk Management Laboratory, Cincinnati, OH.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/. Accessed [April/08/2016]

U.S. Geological Survey, 2012, National Water Information System data available on the World Wide Web (USGS Water Data for the Nation), accessed [April 25, 2016], at URL [http://waterdata.usgs.gov/nwis/inventory?agency_code=USGS&site_no=413102087510901].

U.S. Geological Survey, 2012, National Water Information System data available on the World Wide Web (USGS Water Data for the Nation), accessed [April 25, 2016], at URL [http://waterdata.usgs.gov/nwis/inventory?agency_code=USGS&site_no=420745088025901].

Water and Atmospheric Resources Monitoring Program. Illinois Climate Network. (2015). Illinois State Water Survey, 2204 Griffith Drive, Champaign, IL 61820-7495. http://dx.doi.org/10.13012/J8MW2F2Q.;

Water-Research. http://www.water-research.net/Waterlibrary/Stormwater/greenamp.pdf (Synthesized from Handbook of Hydrology, D.R. Maidment, Editor in Chief, McGrawHill, Inc., 1993, pp 5.1-5.39.).

Appendix A – RECOMMENDED APPROACH TECHNICAL MEMORANDUM

March 15, 2016
File: 174334026

Attention: Joseph Roth
Restoration Programs Director
Openlands
25 East Washington Street
Chicago, IL 60602

Reference: Ecosystem Restoration and Hydrology Changes Tool – Recommended Approach Technical Memorandum

Dear Mr. Roth,

Stantec Consulting Services Inc. (Stantec) has partnered with Wills Burke Kelsey Associates (WBK) and Huddleston McBride Land Drainage Co. for professional services related to the referenced project. The goal of the project is to develop a tool or methodology that users may implement to determine if there is a quantifiable storm water benefit (specifically quantity and/or rate of release) related to landscape-level ecosystem restoration. The team is tasked to: 1) conduct a literature search and prepare a summary of findings; 2) convene a stakeholder conference and prepare a summary report; 3) develop the final tool; and 4) apply the tool to two Openlands restoration sites. This technical memorandum represents the summary report in Task 2.

SUMMARY

The team first reviewed existing data and conducted a search on peer reviewed literature associated with existing tools or models and published methodologies. The review focused on tools that were data-driven, replicable, practical, and based on accepted, peer-reviewed methodologies. A preliminary hydrologic assessment methodology was developed, primarily based on water budget and mass balance approaches. A model-based workflow for quantifying water budget inputs and outputs and hydrologic/hydraulic processes was developed, after which case studies were run on test sub-watersheds on the Deer Grove East and Tinley Creek Wetlands sites.

Stantec, its partners, and Openlands assembled for a conference on Tuesday, January 12, 2016 to discuss and review the methodology recommendations and to review the case study results. This technical memorandum summarizes the literature search, recommended methodology development, recommended model selection, and technical aspects of recommended model construction and parameterization.

Reference: Ecosystem Restoration and Hydrology Changes Tool – Recommended Approach Technical Memorandum

LITERATURE SEARCH AND PEER OUTREACH

The project team conducted a search for established methodologies for assessing hydrologic change on an ecosystem or landscape level, and for a tool or model that could simulate the hydrologic cycle to account for volume and flow changes after ecosystem restoration and hydrologic modifications. Search items include articles in peer-reviewed journals, academic dissertations and theses, textbooks, and government publications. Review of over 100 documents returned 33 items that were useful in methodology development and tool selection (see Appendix A). A number of themes emerged during review of these documents, including:

- water budget and mass balances are critical for understanding wetland hydrology;
- assessment cost and complexity are directly related;
- one should use the simplest level of assessment that is appropriate to meet project goals;
- modeling applied to water balances can predict hydrologic changes and system responses;
- modeling can reduce time and cost for understanding site hydrology, particularly in early site assessment;
- calibrated models can inform hydrologic and hydraulic design and vegetative selection; and
- modeling outputs confirm conceptual understanding of the system, but do not necessarily produce real-world numbers.

Modeling quickly emerged as an important component in the quantitative analysis of hydrologic change, which focused the review on evaluation of potential models for inclusion in the hydrologic assessment methodology. More than 20 models were mentioned in the documents reviewed during the literature search, however, many of these were site or study-specific. Of those with broad applicability, six options were selected for additional consideration: Storm Water Management Model (SWMM), Hydrologic Evaluation of Landfill Performance (HELP), MIKE Système Hydrologique Européen (MIKE SHE), DRAINMOD, MODFLOW, and Wetlands Dynamic Water Budget Model (WDWBM). The models were assessed based on inputs and data needs, model output, scalability, ease of use, ability to simulate water quality effects, software availability, cost, and support, and industry acceptance. A matrix presenting a comparison of the above models is provided in Appendix B.

Reference: Ecosystem Restoration and Hydrology Changes Tool – Recommended Approach Technical Memorandum

Stantec also conducted concurrent outreach to agencies within the region, including: Minnesota Division of Natural Resources (MN DNR), Coon Creek Watershed District (CCWD), Wisconsin Division of Natural Resources (WI DNR), and Illinois State Water Survey (ISWS). Discussions with these groups revealed that monitoring of restoration, particularly for wetlands, is generally limited to tracking site attainment of permit-required performance standards. However, CCWD developed a hydrologic monitoring program, based largely on Brinson's hydrogeomorphic methodology (HGM), for tracking water supply, stormwater, and environmental effects of changes to the conveyance system CCWD maintains. The ISWS tracked hydrologic parameters of a landscape by integrating several models, including SWMM and MODFLOW for a pollution study. During discussion of the Openlands project, ISWS staff recommended SWMM as an appropriate tool for quantifying hydrologic changes in the project landscapes.

RECOMMENDED APPROACH METHODOLOGY

The recommended methodology is presented in Figure 1and follows the general approach of several published studies, and review papers, most notably Acreman and Miller (2007). A conceptual water budget is first formed, based on hydrologic/hydraulic inputs to and outflows from the system. In the second phase, data are acquired and reviewed to frame the scope, precision, and assumptions of future work. Gaps in the existing data, and the need (or not) to fill these gaps are also identified in this stage. In the third stage, the system model is built using the conceptual components initially identified and available site data. The model is then run and calibrated to existing field data until discrepancies are reduced to an acceptable level. Finally, the calibrated models are run under various scenarios to compare pre- and post-restoration system storage and flows.

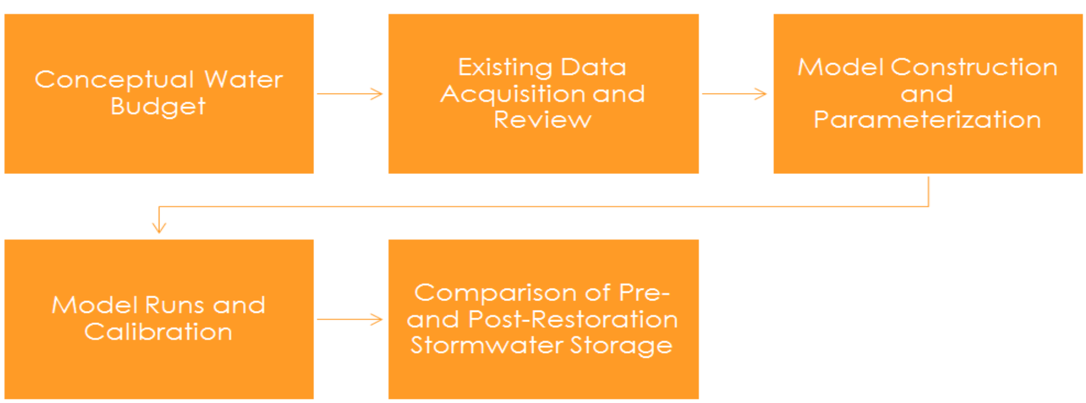


Figure 1. Conceptual structure of recommended landscape hydrologic assessment methodology

Reference: Ecosystem Restoration and Hydrology Changes Tool – Recommended Approach Technical Memorandum

1. MODEL SELECTION

Model selection is critical for the overall success of the recommended assessment methodology. The public domain SWMM software package (current version 5.1.010), developed by the United States Environmental Protection Agency (USEPA), is recommended for volume and flow change quantification as part of the defined approach for the Openlands wetland restoration projects. SWMM is a dynamic rainfall-runoff-routing simulation model that can be used to track the volumes and flows of the hydrologic cycle for a single event or long-term (continuous) simulation. Overland flows can be routed between sub-areas, between sub-catchments, or between entry points of a drainage system. The SWMM model allows for unsteady, non-uniform flow routing. Possible flow regimes include: backwater, reverse flow, surcharging, and surface ponding. The model also contains a flexible set of hydraulic modeling capabilities used to route runoff and external inflows through a drainage system network of pipes, channels, storage/treatment units and diversion structures.

Some of the advantages of the SWMM software are that it has a robust and well-tested computational engine that has been applied in a multitude of applications, is scalable to large/complex watersheds, is open source, and is widely used and well-accepted. The SWMM user interface is more intuitive and user-friendly that some comparable models. Additionally, SWMM was recommended during peer outreach. While software support is limited to a user list serve and help files, the reference documents have been found to be both extensive and useful.

The model can be applicable to a wide range of situations including interconnected watersheds, dual-drainage surfaces, and continuous simulation applications often used for water budgeting. The program has been used throughout the world for planning, analysis and design related to storm water runoff, combined sewers, sanitary sewers, and other drainage systems in urban areas, with many applications in non-urban areas as well, including by the Metropolitan Water Reclamation District of Greater Chicago (MWRD) in their wet weather planning program.

The SWMM model is widely accepted, paired with valuable accompanying technical documentation, and the modeling methodology used is repeatable. The open-source nature of the program and documentation containing mathematical equations offers users the benefit of a program and its methods that has been peer-reviewed for many years. SWMM documentation offers several tables of literature values for input parameters and the models are also capable of receiving inputs and time-series information from existing data collected in the field.

The ecosystem restoration projects are expected to influence several of the hydrological characteristics of the watershed. These items include, but are not limited to, drain tile modification (removal), landuse and vegetation changes (surface roughness, root depth), topography changes (potential storage, slope change), and groundwater changes (specific to piezometric observations). The input parameters in the SWMM model will be adjusted between pre- and post-restoration conditions in order to simulate representative conditions. After making changes to the specified inputs for the post-restoration scenario, the same design or target storm event(s) used for pre-restoration will be simulated to compare the results between base conditions and the alternative scenario.

2. CONCEPTUAL WATER BUDGET

The first step of the recommended approach methodology takes processes of the hydrologic cycle and relates them to components of the SWMM computer model to form a conceptual water budget. The water budget/mass balances are critical for understanding system hydrology. Volume quantification involves accounting for the total water budget and mass balance of the hydrologic cycle within a watershed following the general equation below.

$$\Delta S = [P + S_i + G_i] - [ET + S_o + G_o]$$

where: ΔS = change is system storage
P = precipitation
S_i = surface flow in
G_i = groundwater flow in
ET = evapotranspiration
S_o = surface flow out
G_o = groundwater flow out

Precipitation (SWMM rain gage element) generates time-varying data which is received by a land surface component (SWMM sub-catchment element). Applying the land surface characteristics (user inputs such as slope, percent impervious, soil parameters, etc.), precipitation is then converted to rainfall interception (initial abstraction), evaporation of standing surface water, infiltration into unsaturated soil layers, and surface runoff (nonlinear reservoir routing of overland flow). The surface runoff is typically conveyed hydraulically through a transport network of open channels and pipes (SWMM node and link elements). The infiltration can be routed to the sub-surface via groundwater conveyance (SWMM aquifer element) which can then interflow with the surface flows and/or seep out into deeper ground levels. A schematic of SWMM hydrologic and hydraulic processes is presented in Figure 2.

Reference: Ecosystem Restoration and Hydrology Changes Tool – Recommended Approach Technical Memorandum

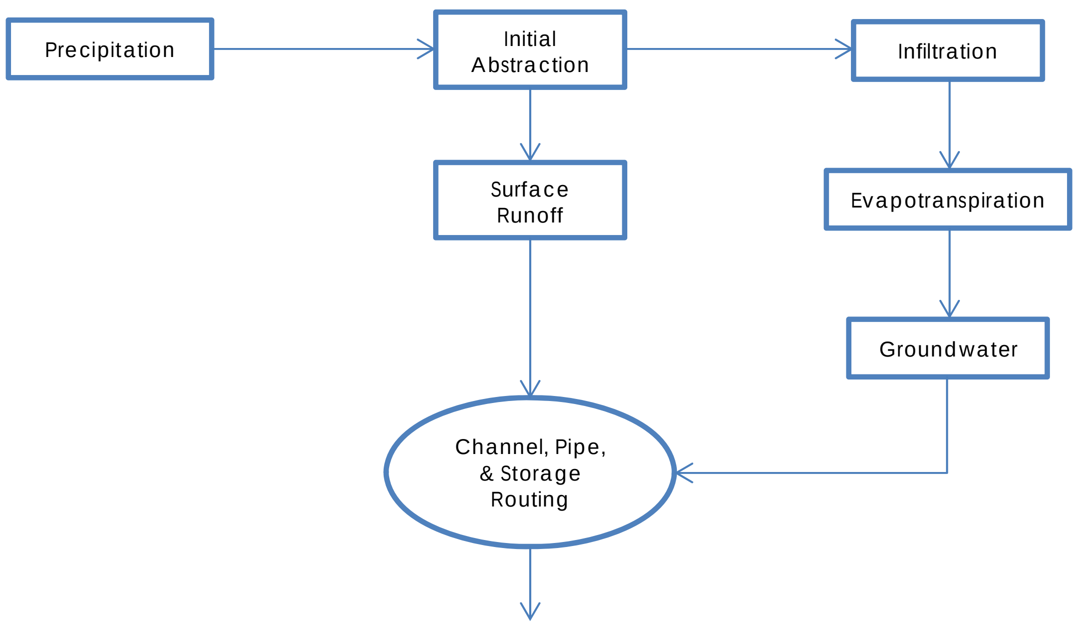


Figure 2. Processes modeled by SWMM. Modified from Rossman (2015).

3. EXISTING DATA ACQUISITION AND REVIEW

The next step is to obtain and review existing data to be used as model inputs. Daily precipitation and evaporation data were acquired from the St. Charles Station through the Water and Atmospheric Resources Monitoring Program (Figure 3) for the preliminary case studies. This site represents the location closest to both test sites with real-world pan evapotranspiration data, and also is in a physiographic location similar to the sites relative to urban areas and Lake Michigan. Review of these data in the model showed that during simulations, intensities for precipitation were distributed evenly over the 24-hour time period. Therefore, the surface runoff values are likely to be underestimated for the dataset containing daily rainfall values. The Midwestern Regional Climate Center has been contacted to inquire about 10-minute rainfall data in the vicinity of the wetland restoration projects. The increased number of data points would provide more precision in the results. Since the project is utilizing a long-term simulation to account for varying degrees of soil saturation and groundwater flows, several months of continuous target storm event data over multiple years is desired. The focus will be on months occurring late-spring through early-fall (i.e. the growing season). With the change in plant community involved in ecosystem restoration, evapotranspiration is expected to have contributed significantly to the hydrologic cycle during this time period. Thus, the source and quality of this data is critical for application of the hydrologic assessment tool.

Reference: Ecosystem Restoration and Hydrology Changes Tool – Recommended Approach Technical Memorandum

Figure 3. ISWS evapotranspiration monitoring sites.

Land surface layer characteristics to be used as sub-catchment data are typically retrieved from aerial imagery and existing topographic contour data. Sub-catchment areas, average percent slope, and width of overland flow path may all be delineated using known topography. The surface roughness, depression storage, and percent impervious values are typically approximated using aerial imagery, field reconnaissance, or detailed site information (e.g. vegetative monitoring data, site photos). Sub-catchment values may be further defined with additional site survey and/or field investigation.

The SWMM infiltration and sub-surface aquifer calculations require inputs for specific soil characteristics. For approximate soil types and their respective values, existing soil data may be attained through United Natural Resources Conservation Service (NRCS) soil surveys or site-specific soil sampling. Parameters such as hydraulic conductivity, wilting point, and field capacity can be found once general soil types are known by using the SWMM Reference Manual – Volume I – Hydrology. Soil borings and subsequent analysis may yield the soil types and their respective characteristics if more detailed information is required. Site monitoring forms from field visits during spring 2015 within the Openlands project areas provided soil descriptions used in preliminary SWMM models. The Modified Green-Ampt infiltration method is expected to be used for the analysis due to the known soil types and to keep the surface and aquifer infiltration parameters consistent.

The sub-surface layer of the SWMM model utilizes several pieces of information collected from the restoration areas. The Tinley Creek Wetlands O'Hare Modernization Mitigation Account (OMMA) Project 2014 Monitoring Report is a good example of the documentation available. Monitoring

Reference: Ecosystem Restoration and Hydrology Changes Tool – Recommended Approach Technical Memorandum

well locations and their data are available for several time periods at the Openlands project sites. The data at each well provides an indication to where the bottom of the aquifer is located and the approximate starting point for a water table elevation. The monitoring wells also offer existing data to calibrate against. The reports describe the vegetation types and their location within the wetlands. Along with the expected pervious roughness n-value, the vegetation data helps to derive a species root depth which offers practical information for modeling the lower evaporation depth. Finally, an existing drain tile review was performed for the modification and abandonment plans. The existing data offers tile location, size, conditions and the approximate depth of the invert elevation below ground. Each of these drain tile bits of information contributes toward the modeling of the sub-surface aquifer layer and accounting of groundwater flow.

4. MODEL CONSTRUCTION AND PARAMETERIZATION

The layout of the pre- and post-restoration models will visually appear similar. The basic visual components of the sub-catchment area and hydraulic network, as described in Section 1 – Conceptual Water Budget, should display as nearly identical with the exception of a few modifications to the drain tile network. As mentioned in the existing data acquisition section above, the majority of the visible model will be constructed from aerial imagery, topographic data, and site survey. The model will be built on top of a geo-referenced image of the project sites so contributing areas within the project sites are accounted for. Much of the project sites analyzed will have negligible impervious area in both the before and after conditions. The sub-catchment areas, average slopes, and flow path lengths are unlikely to deviate between the two models without large amounts of grading. Additionally, the soil types are likely to remain consistent between pre- and post-restoration scenarios.

The significant changes will occur behind the scenes within specific entities' parameterization fields and the non-visual components of the model. Expected changes between the two models will take place within the climatology (evaporation time series data edits for vegetation changes), aquifers (drain tile hydraulic network edits and root depth), and landuse (Manning's "n-value" for sub-catchment roughness and changes in stage-storage curves for altered topography).

Climatology

Changing the vegetation during the wetland restoration process is expected to increase both evaporation (increased surface storage) and evapotranspiration (change in species and increased root depths). During continuous-simulations, evaporation and evapotranspiration become a significant factor in the water budget, particularly during the non-wet drying periods. Regional data are used for daily evaporation. "Crop coefficients" will be used as outlined in the Food and Agriculture organization (FAO) Irrigation and Drainage Paper 56 (Allen et al., 1998) to account for changes in evapotranspiration. The crop coefficient method was also examined as the American Society of Civil Engineers (ASCE) Standardized Reference Evapotranspiration Equation final report (2005).

Reference: Ecosystem Restoration and Hydrology Changes Tool – Recommended Approach Technical Memorandum

The crop coefficient method uses the Penman-Monteith evaporation equation to create a standard reference potential evapotranspiration value, which can then be scaled to a variety of different crop types by multiplying the value by the appropriate crop coefficient. Beginning in December 2011, the ISWS Illinois Climate Network started calculating the daily potential evapotranspiration using the necessary techniques in order for this data to be utilized.

The single crop coefficient $K_{c\ mid}$ for the specified vegetation (Table 12 in Allen et al, 1998) will be multiplied by the evaporation data timeseries to account for the changing plant types during restoration activities.

Aquifers

The groundwater option within a SWMM model requires the user to create aquifers. This component is necessary to model the long term effects of the hydrologic cycle. Although there is not a direct input for creating drain tiles, modelers can calculate coefficients from Hooghoudt's Equation (Figure 4) in order to simulate the effects of the tile drainage. The method reduces a series of simultaneous equations to simple functions of drain spacing, drain diameter, and depth to the impermeable soil layer.

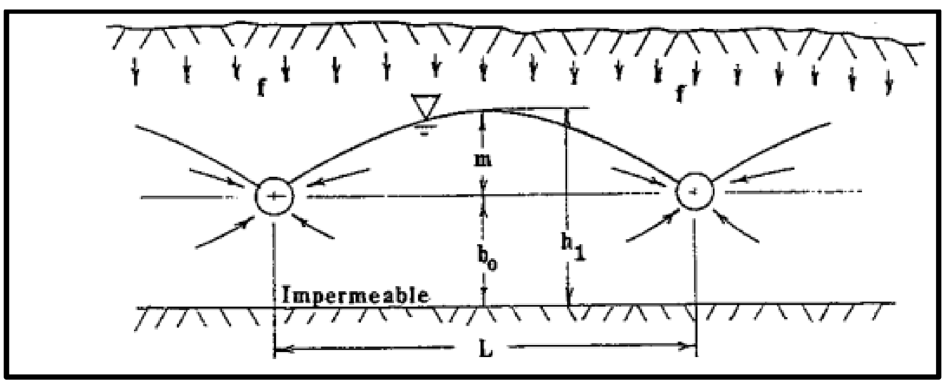


Figure 4. Sketch of variables used in Houghoudt's calculation of drain tile hydraulics.

Within the "Groundwater Flow Editor", there is an input for the node that receives groundwater flow from the aquifer. Typically in watersheds with tile drainage, this would be the downstream tile node. The modeler will zero out the Hooghoudt Method coefficients and change the receiving node to one that has an invert at the ground surface for post-restoration conditions where drain tile is removed. This methodology will eliminate the transport of groundwater flow while accounting for the groundwater storage and the interflow of groundwater and surface drainage.

Reference: Ecosystem Restoration and Hydrology Changes Tool – Recommended Approach Technical Memorandum

Different species of vegetation have different root depths. In order to account for the variations in root depth, the modeler has the capability to modify the "Lower Evaporation Depth" within the "Aquifer Editor". The lower evaporation depth parameter factors in the depth into the saturated zone over which evaporation can occur. As an example, the Deer Grove East case study site had Eurasian Meadow Grass planted pre-restoration. This plant has a known root depth of approximately 24 inches. Native Prairie, Forb Dominated with a rooting depth of 84 inches was the vegetation used post-restoration (CRI, 1995). The increase in root depth showed increased lower zone evapotranspiration losses as expected. Change in root depth will be accounted for using the lower evaporation depth methodology.

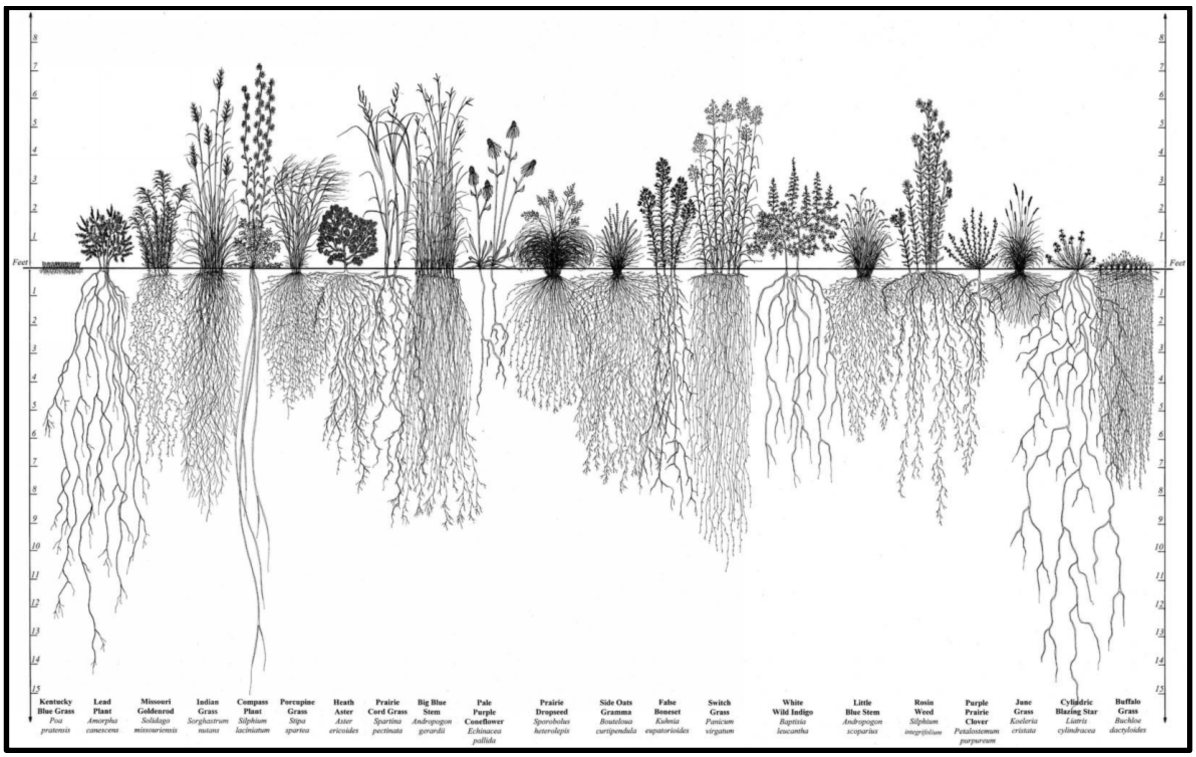


Figure 5. Rooting depth of native prairie plants. From CRI (1995).

Landuse

Changes in landuse between the two scenarios will likely have impacts to the surface roughness and detention storage. Each sub-catchment has an input for the Manning's roughness "N-value" for pervious and impervious overland flow areas. Depending on the vegetation, surface roughness typically increases from existing conditions as wetlands are restored and the density of plant life increases.

During ecosystem restoration, topography modifications may also be used for increased detention and storage. Using the proposed contours, modelers can simulate the detention space by modeling storage nodes with defined stage-storage curves. Increased storage results in decreased peak runoff flow rates.

5. MODEL RUNS AND CALIBRATION

The model produces results using the specified meteorological data and simulation times after the pre- and post-restoration models are constructed with the changes to climatology, aquifer parameters, and landuse in place. Calibration is then performed using observed data to compare the modeled results against. Examples of observed data include surface storage, flow monitoring, and piezometric observations. Depending on when the observed data was collected, calibration could either be for pre- or post-restoration conditions so long as the other scenario has matching parameters that one would expect to stay consistent between the two simulations.

Many parameters can be used to calibrate a model, however; sub-catchment area should not change, and parameters like percent impervious, average slope and flow path width will have minimal variation due to the elevated certainty in the smaller watersheds. Other parameters may vary, especially those that cannot be directly measured such as surface roughness and the evapotranspiration crop coefficients. Additionally, infiltration parameters and aquifer parameters like conductivity slope, tension slope, upper evaporation fraction, and lower groundwater loss rate may all be adjusted to increase confidence in the modeled results when comparing to observed values.

6. COMPARISON OF PRE- AND POST-RESTORATION STORMWATER STORAGE

The modeler will perform final model runs over the duration of the growing season and/or target storm events for both sites after construction and calibration of the full models. The SWMM software will perform calculations to account for volume and flow change quantification as they relate to the watershed for pre- and post-restoration conditions.

Results will be compared between the two scenarios to identify whether or not there is a quantifiable storm water benefit related to wetland and upland restoration of native plant communities. The status report within the model offers information the user can export to analyze the water budget and hydrologic cycle. Information such as total precipitation, evaporation and infiltration loss, surface runoff, initial and final storage, upper and lower zone ET, deep percolation and groundwater flows are some of the summary outputs. The modeler should be able to provide an assessment of the expected hydrologic effects of restoration based on the simulated data and results.

7. TEST CATCHMENT RESULTS

Water budgets generated for the test catchments are presented in Figure 6 and Figure 7. Both systems showed similar responses to restoration activities; most notably decreases in groundwater outflow, increases in groundwater recharge, and increases in deep evapotranspiration. Groundwater effects are likely the result of drain tile disabling, while the increase in deep evapotranspiration likely reflects the increased rooting depth of planted native prairie species replacing shallow-rooted pre-restoration warm-season grasses. Overall system response is consistent with what was anticipated based on the literature review and previous experience. Additionally, calibration data (Figure 8) suggest proper parameterization for the test models.

Reference: Ecosystem Restoration and Hydrology Changes Tool – Recommended Approach Technical Memorandum

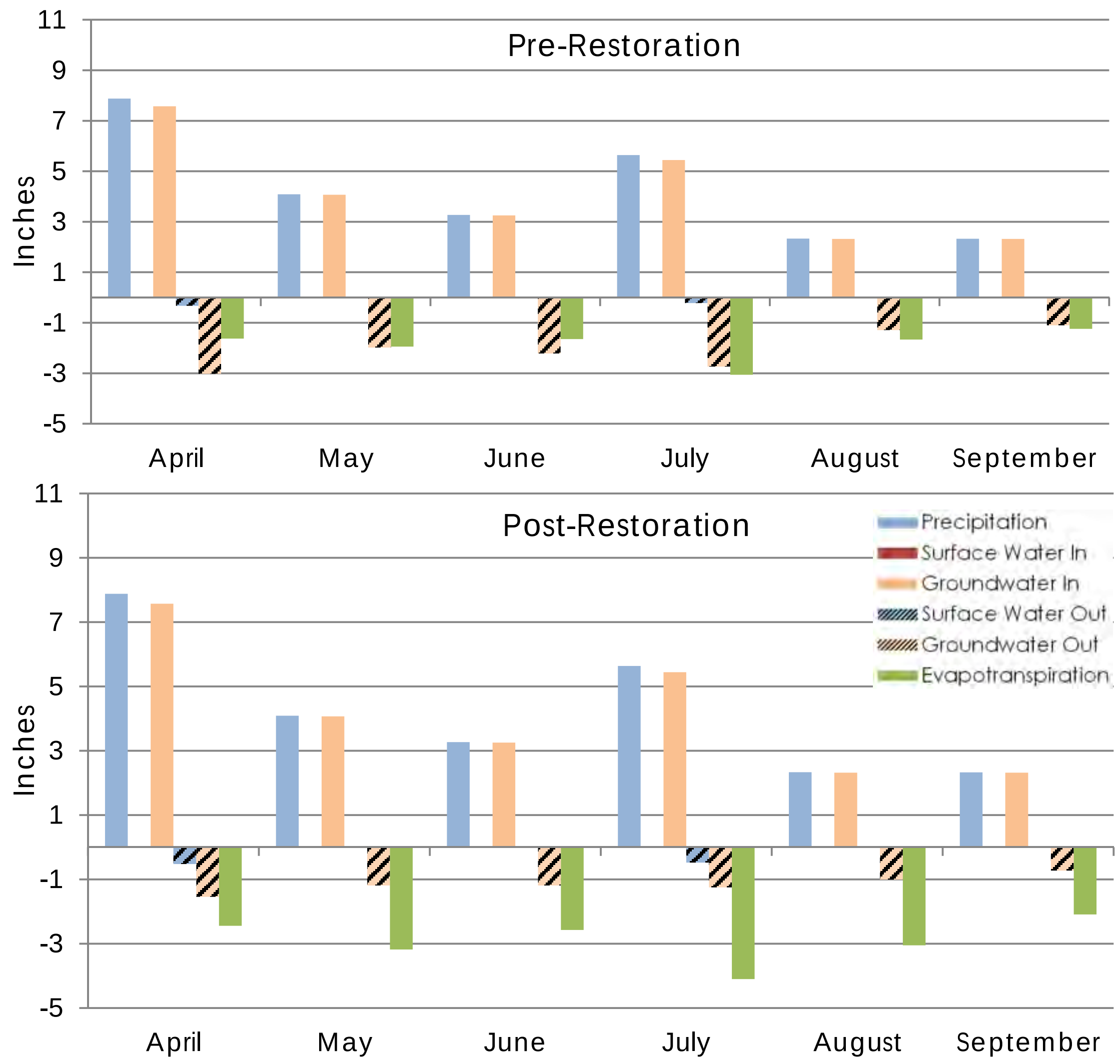


Figure 6. SWMM-generated water budgets for Deer Grove East test sub-catchment.

**Surface water in = sheet and channel flow; Groundwater in = drain tile inflow and groundwater discharge; Groundwater out = drain tile outflow and groundwater recharge; Evapotranspiration = surface and shallow soil evaporation and transpiration from deep root zone.*

Reference: Ecosystem Restoration and Hydrology Changes Tool – Recommended Approach Technical Memorandum

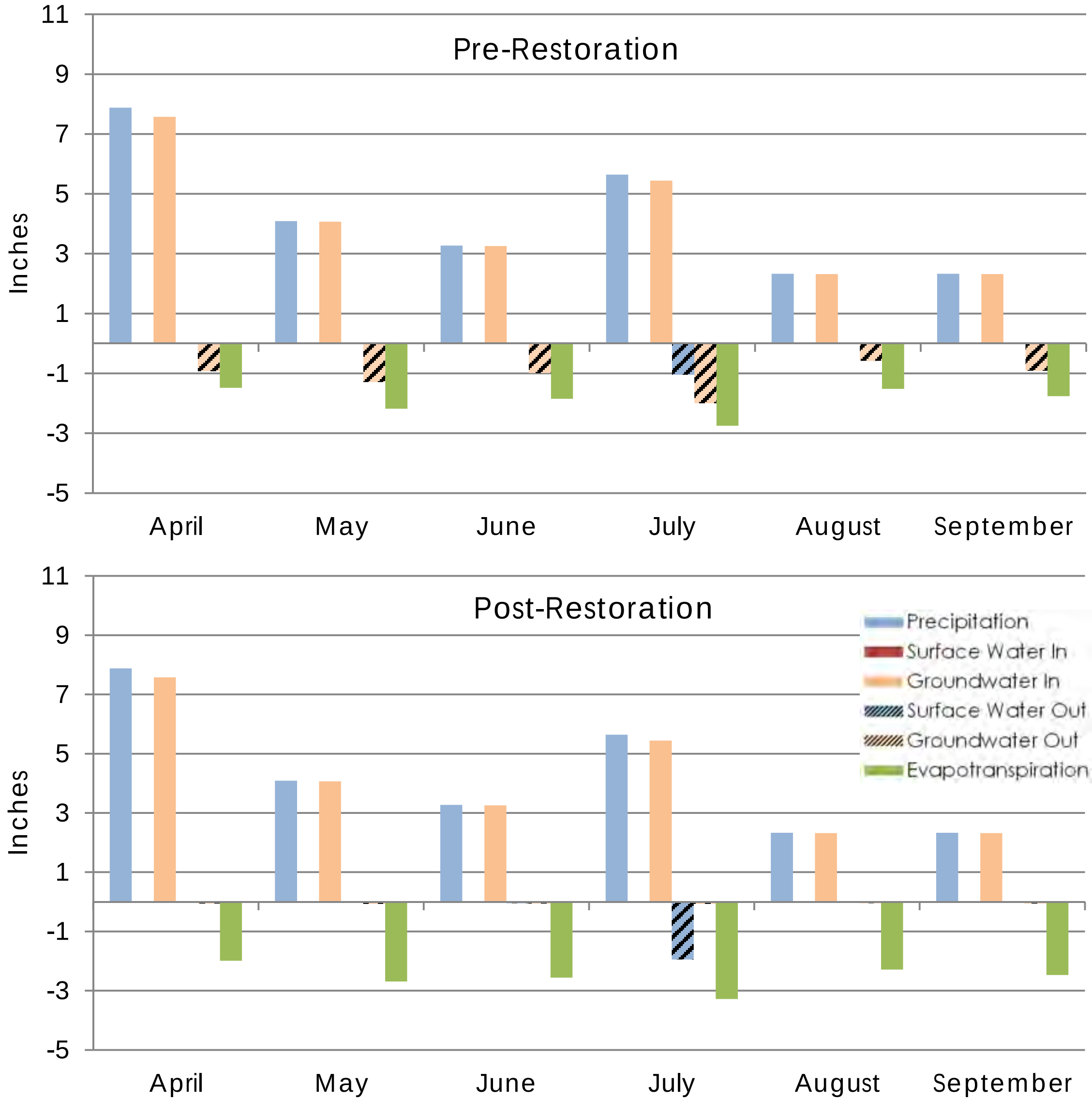


Figure 7. SWMM-generated water budgets for Tinley Creek Wetlands test sub-catchment.

**Surface water in = sheet and channel flow; Groundwater in = drain tile inflow and groundwater discharge; Groundwater out = drain tile outflow and groundwater recharge; Evapotranspiration = surface and shallow soil evaporation and transpiration from deep root zone.*

Reference: Ecosystem Restoration and Hydrology Changes Tool – Recommended Approach Technical Memorandum

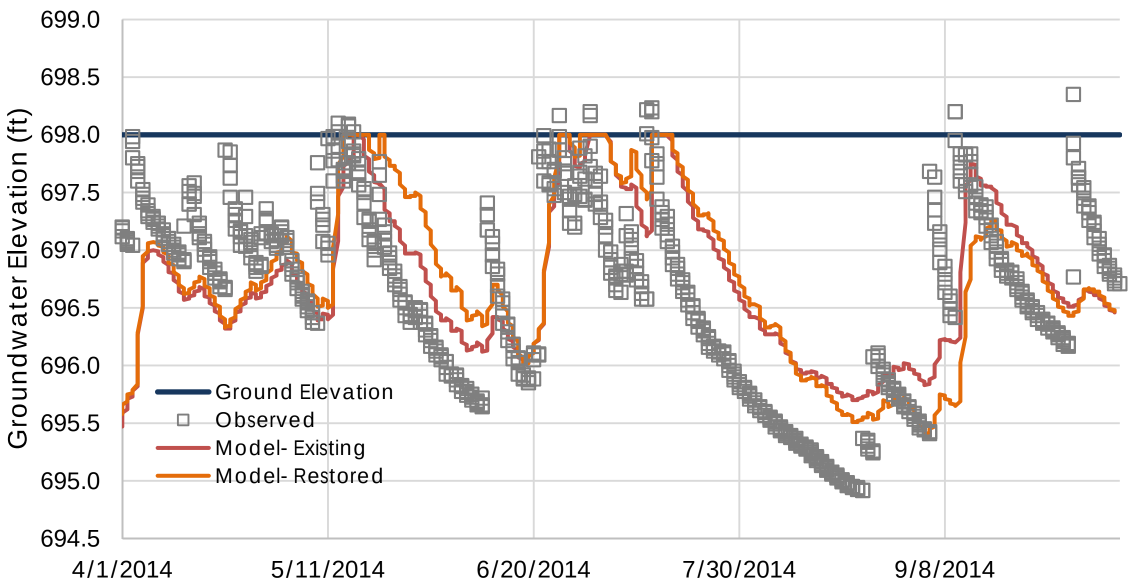


Figure 8. Calibration results for Tinley Creek Wetlands test sub-catchment model.

Test sub-catchment results support the conceptual structure for the recommended hydrologic change assessment methodology. Based on the successful test runs, Stantec recommends moving forward with applying the recommended methodology to the full Deer Grove and Tinley Creek Wetlands sites.

Regards,

Scott Peyton, P.E.
Senior Principal
Phone: (513) 842-8217
scott.peyton@stantec.com

REFERENCES

Acreman, M.C., J. Fisher, C.J. Stratford, D.J. Mould, and J.O. Mountford. 2007. Hydrological Science and Wetland Restoration: Some Case Studies form Europe. Hydrology and Earth System Sciences 11(1):158-169.

Allen, R., Pereira, L., Raes, D., and Smith, M. (1998) Crop evapotranspiration – Guidelines for computing crop water requirements FAO – Food and Agriculture Organization of the United Nations. Rome, Italy.

American Society of Civil Engineers. 2005. The ASCE Standardized Reference Evapotranspiration Equation. ASCE-EWRI Task Committee Report. ASCE, Reston, VA.

Conservation Research Institute. 1995. Root Systems of Prairie Plants. Educational Poster. CRI, Cedarburg, WI.

Rossman, L. 2015. Storm Water Management Model Reference Manual Volume I – Hydrology. EPA-600-R-15-162. USEPA National Risk Management Laboratory, Cincinnati, OH.

Reference: Ecosystem Restoration and Hydrology Changes Tool – Recommended Approach Technical Memorandum

APPENDIX A – PERTINENT ITEMS FROM LITERATURE REVIEW

Acreman, M.C., J. Fisher, C.J. Stratford, D.J. Mould, and J.O. Mountford. 2007. Hydrological Science and Wetland Restoration: Some Case Studies form Europe. Hydrology and Earth System Sciences 11(1):158-169.

Acreman, M.C. and F. Miller. 2007. Hydrological Impact Assessment of Wetlands. In: The Global Importance of Gr.oundwater in the 21st Century. S. Ragone, A. de la Hera, N. Hernandez-Mora (eds). NGWA Press, Westerville, OH.

Allen, R., Pereira, L., Raes, D., and Smith, M. (1998) Crop evapotranspiration – Guidelines for computing crop water requirements FAO – Food and Agriculture Organization of the United Nations. Rome, Italy.

American Society of Civil Engineers. 2005. The ASCE Standardized Reference Evapotranspiration Equation. ASCE-EWRI Task Committee Report. ASCE, Reston, VA.

Bengston, M.L. and G. Padmanabhan. 1999. A Review of Models for Investigating the Influence of Wetlands on Flooding. Report Submitted to International Joint Commission Red River Task Force. North Dakota Water Resources Research Institute, Fargo, ND.

Biebighauser, T.R. 2007. Wetland Drainage, Restoration, and Repair. The University Press of Kentucky, Lexington, KY.

Bullock, A. and M. Acreman. 2003. The Role of Wetlands in the Hydrological Cycle. 2003. Hydrology and Earth System Sciences 7(3):358-389.

Caldwell, P.V., M.J. Veraskas, J.D. Gregory, R.W. Skaggs, and R.L. Huffman. 2011. Linking Plant Ecology and Long-Term Hydrology to Improve Wetland Restoration Success. Transactions of the American Society of Agricultural and Biological Engineers 54(6):2129-2137.

Conservation Research Institute. 1995. Root Systems of Prairie Plants. Educational Poster. CRI, Cedarburg, WI.

Costanza, R. and F.H. Sklar. 1985. Articulation, Accuracy, and Effectiveness of Mathematical Models: A Review of Freshwater Wetland Applications. Ecological Modeling 27:45-68.

Dai, Z., D.M. Amatya, G. Sun, C.C. Trettin, C. Li, and H. Li. 2010. A Comparison of MIKE SHE and DRAINMOD for Modeling Forested Wetland Hydrology in Coastal South Carolina, USA.

Reference: Ecosystem Restoration and Hydrology Changes Tool – Recommended Approach Technical Memorandum

Conference Paper Presented at the American Society of Agricultural and Biological Engineers 9th International Drainage Symposium, Quebec City, Canada.

Demissie, M., A.A. Akanbi, and A. Khan. 1997. Hydrologic Modeling of Landscape Functions of Wetlands. Research Report 125. Illinois State Water Survey, Champaign, IL.

Fitz, H.C. and N. Hughes. 2008. Wetland Ecological Models. UF/IFAS Document SL257. University of Florida, Gainesville, FL.

Glivear, D.J., and C. Bradley. 2000. Hydrological Monitoring and Surveillance for Wetland Conservation and Management: a UK Perspective. Physics and Chemistry of the Earth 25(7-8): 571-588.

Harbaugh, A.W. 2005. MODFLOW-2005, The U.S. Geological Survey Modular Ground-Water Model-the Ground-Water Flow Process. U.S. Geological Survey Techniques and Methods 6-A16. USGS, Reston, VA.

Harbor, J.M. 1994. A Practical Method for Estimating the Impact of Land-Use Change on Surface Runoff Groundwater Recharge and Wetland Hydrology. Journal of the American Planning Association 60(1):95-108.

Hooijer, A. 2003. Quantifying Wetland Hydrological Functions: Some Examples of Innovative Methods Using Water Table Information. Conference Paper Presented at the 1st Annual WETHYDRO Workshop, Gonadz, Poland.

Mitsch, W.J. and J.G. Gosselink. 2000. Wetlands. 3rd Edition. John Wiley and Sons, New York, NY.

Obropta, C., P. Kallin, M. Mak, and B. Ravi. 2008. Modeling Urban Wetland Hydrology for the Restoration of a Forested Riparian Wetland Ecosystem. Urban Habitats 5(1):183-198.

Olszewski, J.M. and R.H. McCuen. 2014. Modeling of Wetland Systems. In: Handbook of Engineering Hydrology: Environmental Hydrology and Water Management. Saeid Eslamian, ed. CRC Press, Boca Raton, FL.

Owen, C.R. 1995. Water Budget and Flow Patterns in an Urban Wetland. Journal of Hydrology 169:171-187.

Petru, B.J., G.M. Chescheir, and C. Ahn. 2014. Assessment of Water Budgets and the Hydrologic Performance of a Created Wetland – a Modeling Approach. Ecological Engineering 71:667-676.

Pierce, G.J. 1993. Planning Hydrology for Constructed Wetlands. WTI 93-2. Wetland Training Institute, Inc., Poolesville, MD.

Prucha, R.H. 2004. Review of MIKE SHE. Southwest Hydrology 3(1):37.

Rossman, L. 2015. Storm Water Management Model Reference Manual Volume I – Hydrology. EPA-600-R-15-162. USEPA National Risk Management Laboratory, Cincinnati, OH.

Schroeder, P.R., T.S. Dozier, P.A. Zappi, B.M. McEnroe, J.W. Sjostrom, and R.L. Peyton. 1994. The Hydrologic Evaluation of Landfill Performance (HELP) Model: Engineering Documentation for Version 3. EPA-600-9-94. USEPA Risk Reduction Engineering Laboratory, Cincinnati, OH.

Skaggs, R.W. 1980. DRAINMOD Reference Report: Methods for Design and Evaluation of Drainage-Water Management Systems for Soils with High Water Tables. USDA-NRCS South National Technical Center, Fort Worth, TX.

Skaggs, R.W., G.M. Chescheir, and B.D. Phillips. 2005. Methods to Determine Lateral Effect of a Drainage Ditch on Wetland Hydrology. Transactions of the American Society of Agricultural Engineers 48(2): 577-584.

Trepel, M, M. Dall'O', L. Dal Cin, M. De Wit, S. Optiz, L. Palmeri, J. Persson, N. M. Pieterse, T. Timmermann, G. Bendoricchio, W. Kluge, and S.E. Jørgensen. 2000. Models for Wetland Planning, Design, and Management. EcoSys Bd. 8: 93-137.

Troidl, J.C. 2007. A Storm Water Management Model to Predict Runoff and Streamflow in the Pennichuck Brook Watershed. Master's Thesis, Cornell University, Ithica, NY.

USACE. 1997. Wetlands Dynamic Water Budget Model. WRP Technical Note HY-CP-5.2. Army Engineer Waterways Experiment Station, Vicksburg, MS.

USEPA. 2008. Methods for Evaluating Wetland Condition: Wetland Hydrology. EPA-822-R-08-024. Office of Water, USEPA, Washington, DC.

Walton, R., R.S. Chapman, and J.E. Davis. 1996. Development and Application of the Wetlands Dynamic Water Budget Model. Wetlands 16(3):347-357.

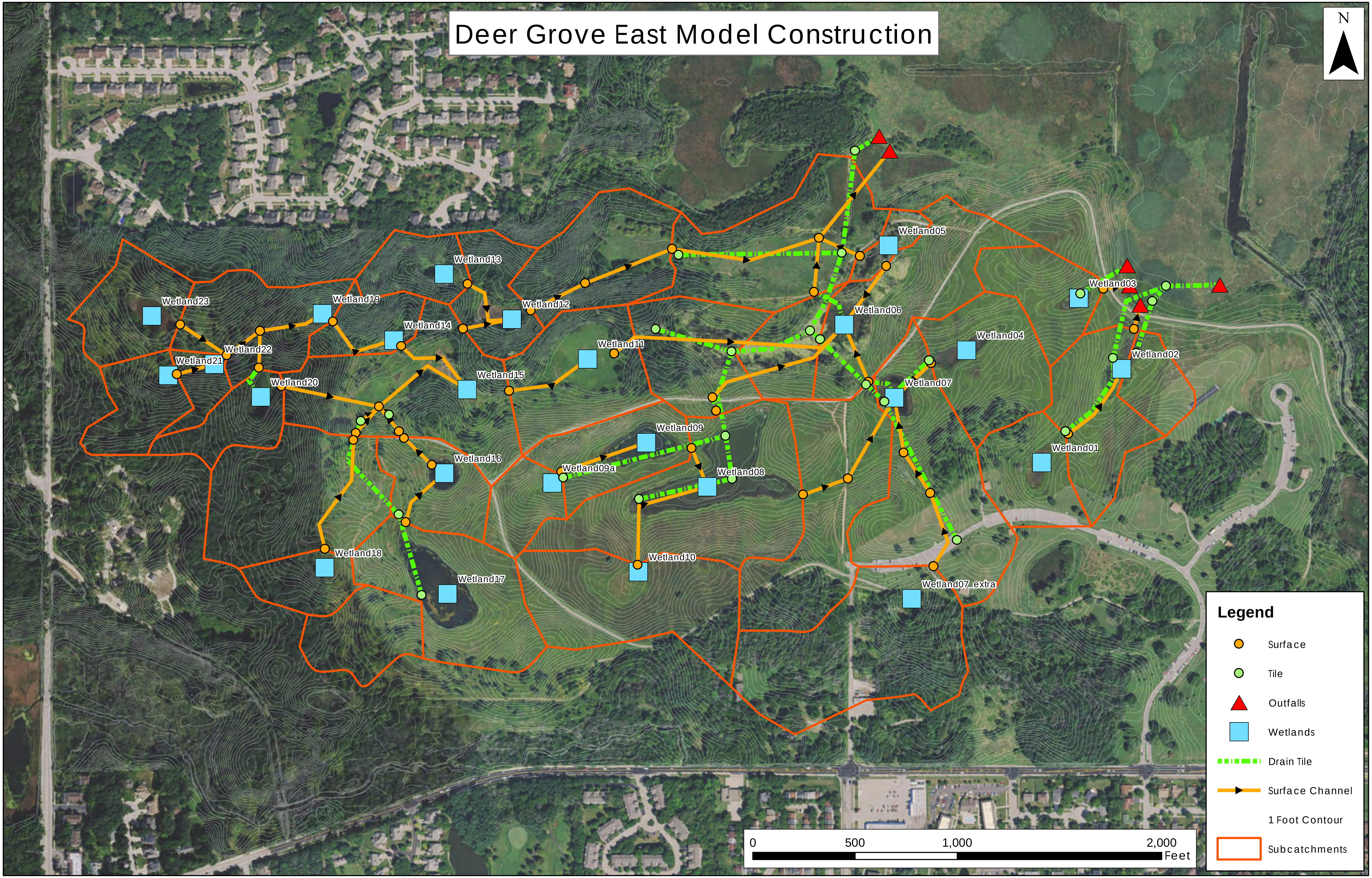
Reference: Ecosystem Restoration and Hydrology Changes Tool – Recommended Approach Technical Memorandum

APPENDIX B – POTENTIAL MODEL MATRIX

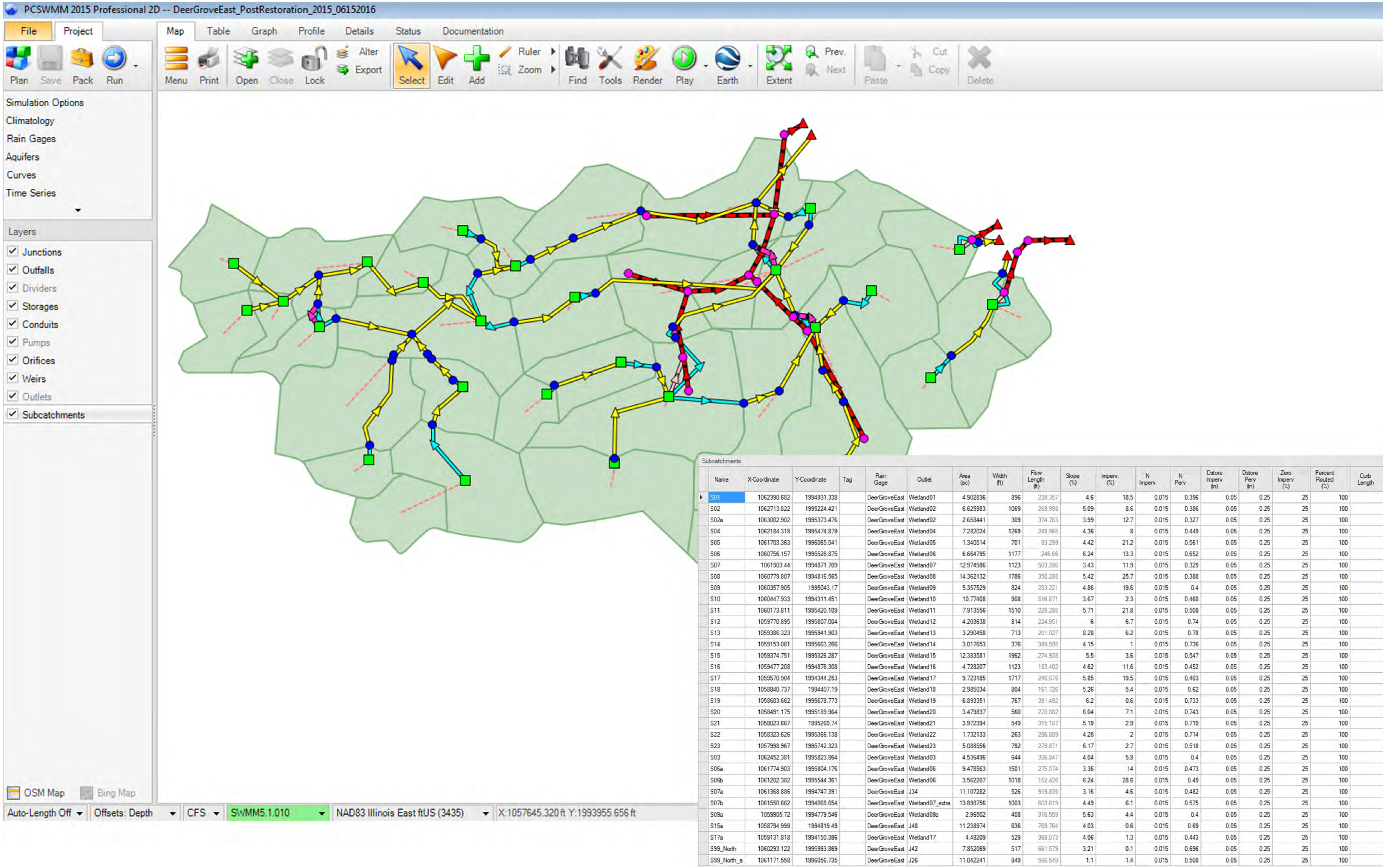
OPENLANDS ECOSYSTEM RESTORATION AND HYDROLOGY CHANGES TOOL POTENTIAL MODEL MATRIX

Model	Developer	Inputs/Data Needs	Output	Water Quality	Availability	Limitations	Advantages
EPA SWMM	USEPA	Precipitation; subcatchment area; hydrologic network; soils; aquifer properties; drainage system properties; landcover/impervious area; DEM/elevation; ET	Q, d, Q groundwater; GW elevation at each network component; Hydrograph; groundwater depth at model outlet	Yes	Open Source/PC SWMM available at cost	Freeware GUI requires user to develop GIS linkage; support limited to (quite good) help files and user list serve	Robust and well-tested computation engine; scalable to large/complex watersheds; widely used and well-accepted
DRAINMOD	NCSU	Drainage depth; ditch spacing; surface detention; roughness; vegetation; soils; ET;	Surface runoff, infiltration, drainage runoff, water table depth	Nitrogen and Salt only	Open Source	More “black box” approach; must link multiple model files to model above sub-catchment level	Specifically addresses drain tillage; direct water budget output; multiple soil layer simulation
HELP	USEPA	Precipitation; temperature; solar radiation; vegetation; soils; slope; drainage parameters	Surface runoff; ET, drainage	No	Open Source	No surface storage; limited to single catchment	Can simulate sub-grade drainage; multiple soil layer simulation; fairly robust vegetation/ET mechanics
MODFLOW	USGS	Hydraulic conductivity; potentiometric head; specific storage; volumetric flow	Vertical and horizontal flow; flownets; flow vector fields	With MT3DMS module	Open Source	Groundwater only; requires specialized training	Most robust modeling of groundwater flow; output can be coupled with surface/channel models
MIKE SHE	DHI	DEM/elevation; soils; vegetation; drainage network; precipitation; ET	Surface runoff; channel runoff; groundwater flow; ET	Yes	Proprietary Software Package	Potentially large data input and long processing time; requires specialized training; expensive ($10,000 for full license)	Used in Everglades hydrologic restoration projects; can use spatial data directly; extensive modeling capability
WDWBM	USACE	Precipitation; ET; hydrologic network; groundwater flow; vegetation	ET; channel flow; saturated groundwater flow	No	Unknown	Vegetation effect limited to canopy interception: Unknown if support continued	Wetland-specific; direct water budget output;

Appendix B – MODEL CONSTRUCTION FIGURES



Deer Grove East Model Construction
N
Wetland05
Wetland13
Wetland03
Wetland12
Wetland23
Wetland19
Wetland06
Wetland14
Wetland04
Wetland11
Wetland02
Wetland22
Wetland21
Wetland15
Wetland07
Wetland20
Wetland09
Wetland01
Wetland16
Wetland09a
Wetland08
Wetland18
Wetland10
Wetland17
Wetland07_extra
Legend
Surface
Tile
Outfalls
Wetlands
Drain Tile
Surface Channel
1 Foot Contour
Subcatchments
0
500
1,000
2,000
Feet



Name	X-Coordinate	Y-Coordinate	Tag	Rain Gage	Outlet	Area (ac)	Width (ft)	Flow Length (ft)	Slope (%)	Imperv. (%)	N Imperv	N Perv	Dstore Imperv (in)	Dstore Perv (in)	Zero Imperv (%)	Percent Routed (%)	Curb Length
S01	1062390.682	1994931.338		DeerGroveEast	Wetland01	4.902836	896	238.357	4.6	18.5	0.015	0.396	0.05	0.25	25	100	0
S02	1062713.822	1995224.421		DeerGroveEast	Wetland02	6.625983	1069	269.998	5.09	8.6	0.015	0.386	0.05	0.25	25	100	0
S02a	1063002.902	1995373.476		DeerGroveEast	Wetland02	2.658441	309	374.763	3.99	12.7	0.015	0.327	0.05	0.25	25	100	0
S04	1062184.318	1995474.879		DeerGroveEast	Wetland04	7.282024	1269	249.965	4.36	8	0.015	0.449	0.05	0.25	25	100	0
S05	1061703.363	1996065.541		DeerGroveEast	Wetland05	1.340514	701	83.299	4.42	21.2	0.015	0.561	0.05	0.25	25	100	0
S06	1060756.157	1995526.875		DeerGroveEast	Wetland06	6.664795	1177	246.66	6.24	13.3	0.015	0.652	0.05	0.25	25	100	0
S07	1061903.44	1994871.709		DeerGroveEast	Wetland07	12.974986	1123	503.286	3.43	11.9	0.015	0.329	0.05	0.25	25	100	0
S08	1060779.807	1994816.565		DeerGroveEast	Wetland08	14.362132	1786	350.288	5.42	25.7	0.015	0.388	0.05	0.25	25	100	0
S09	1060357.905	1995043.17		DeerGroveEast	Wetland09	5.357529	824	283.221	4.86	19.6	0.015	0.4	0.05	0.25	25	100	0
S10	1060447.933	1994311.451		DeerGroveEast	Wetland10	10.77408	908	516.871	3.67	2.3	0.015	0.468	0.05	0.25	25	100	0
S11	1060173.811	1995420.109		DeerGroveEast	Wetland11	7.913556	1510	228.288	5.71	21.8	0.015	0.508	0.05	0.25	25	100	0
S12	1059770.895	1995807.004		DeerGroveEast	Wetland12	4.203638	814	224.951	6	6.7	0.015	0.74	0.05	0.25	25	100	0
S13	1059386.323	1995941.903		DeerGroveEast	Wetland13	3.290458	713	201.027	8.28	6.2	0.015	0.78	0.05	0.25	25	100	0
S14	1059153.081	1995663.266		DeerGroveEast	Wetland14	3.017653	376	349.598	4.15	1	0.015	0.736	0.05	0.25	25	100	0
S15	1059374.751	1995326.287		DeerGroveEast	Wetland15	12.383581	1962	274.938	5.5	3.6	0.015	0.547	0.05	0.25	25	100	0
S16	1059477.208	1994876.308		DeerGroveEast	Wetland16	4.728207	1123	183.402	4.62	11.6	0.015	0.452	0.05	0.25	25	100	0
S17	1059570.904	1994344.253		DeerGroveEast	Wetland17	9.723185	1717	246.676	5.85	19.5	0.015	0.403	0.05	0.25	25	100	0
S18	1058840.737	1994407.19		DeerGroveEast	Wetland18	2.985034	804	161.726	5.26	5.4	0.015	0.62	0.05	0.25	25	100	0
S19	1058603.662	1995678.773		DeerGroveEast	Wetland19	6.893351	767	391.492	6.2	0.6	0.015	0.733	0.05	0.25	25	100	0
S20	1058491.175	1995189.964		DeerGroveEast	Wetland20	3.479837	560	270.682	6.04	7.1	0.015	0.743	0.05	0.25	25	100	0
S21	1058023.667	1995269.74		DeerGroveEast	Wetland21	3.972394	549	315.187	5.19	2.9	0.015	0.719	0.05	0.25	25	100	0
S22	1058323.626	1995366.138		DeerGroveEast	Wetland22	1.732133	263	286.889	4.28	2	0.015	0.714	0.05	0.25	25	100	0
S23	1057998.967	1995742.323		DeerGroveEast	Wetland23	5.088556	792	279.871	6.17	2.7	0.015	0.518	0.05	0.25	25	100	0
S03	1062452.381	1995823.864		DeerGroveEast	Wetland03	4.536496	644	306.847	4.04	5.8	0.015	0.4	0.05	0.25	25	100	0
S06a	1061774.903	1995804.176		DeerGroveEast	Wetland06	9.478563	1501	275.074	3.36	14	0.015	0.473	0.05	0.25	25	100	0
S06b	1061202.382	1995544.361		DeerGroveEast	Wetland06	3.562207	1018	152.426	6.24	28.6	0.015	0.49	0.05	0.25	25	100	0
S07a	1061368.886	1994747.391		DeerGroveEast	J34	11.107282	526	919.835	3.16	4.6	0.015	0.482	0.05	0.25	25	100	0
S07b	1061550.662	1994068.654		DeerGroveEast	Wetland07_extra	13.898756	1003	603.619	4.49	6.1	0.015	0.575	0.05	0.25	25	100	0
S09a	1059905.72	1994779.546		DeerGroveEast	Wetland09a	2.96502	408	316.559	5.63	4.4	0.015	0.4	0.05	0.25	25	100	0
S15a	1058794.999	1994819.49		DeerGroveEast	J48	11.238974	636	769.764	4.03	0.6	0.015	0.69	0.05	0.25	25	100	0
S17a	1059131.818	1994150.386		DeerGroveEast	Wetland17	4.48209	529	369.073	4.06	1.3	0.015	0.443	0.05	0.25	25	100	0
S99_North	1060293.122	1995993.869		DeerGroveEast	J42	7.852069	517	661.579	3.21	0.1	0.015	0.696	0.05	0.25	25	100	0
S99_North_a	1061171.558	1996056.735		DeerGroveEast	J26	11.042241	849	566.549	1.1	1.4	0.015	0.508	0.05	0.25	25	100	0

Appendix C – DEER GROVE EAST CALIBRATION GRAPHS

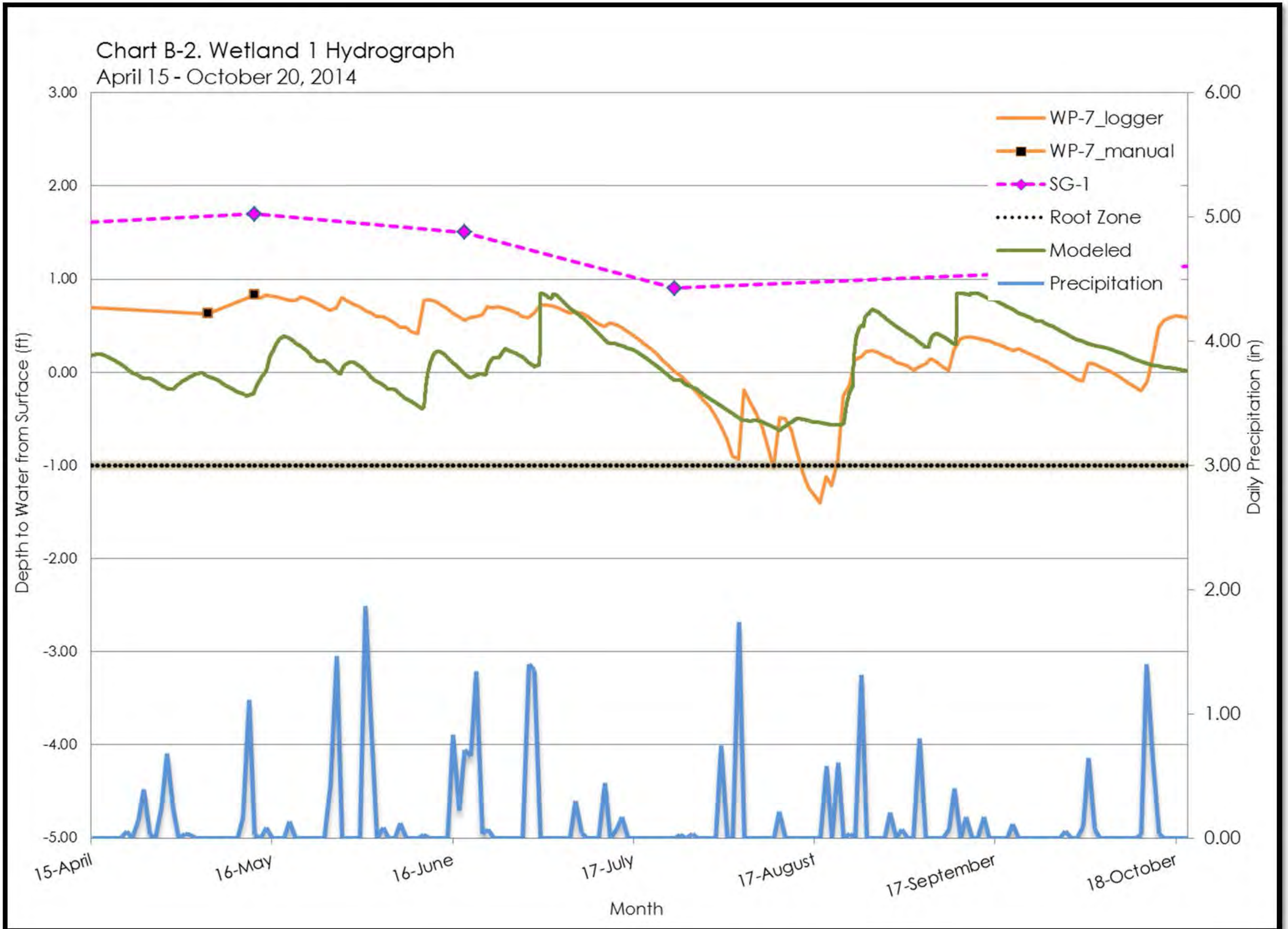


Chart B-2. Wetland 1 Hydrograph
April 15 - October 20, 2014
WP-7_logger
WP-7_manual
SG-1
Root Zone
Modeled
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
15-April
16-May
16-June
17-July
17-August
17-September
18-October
Month

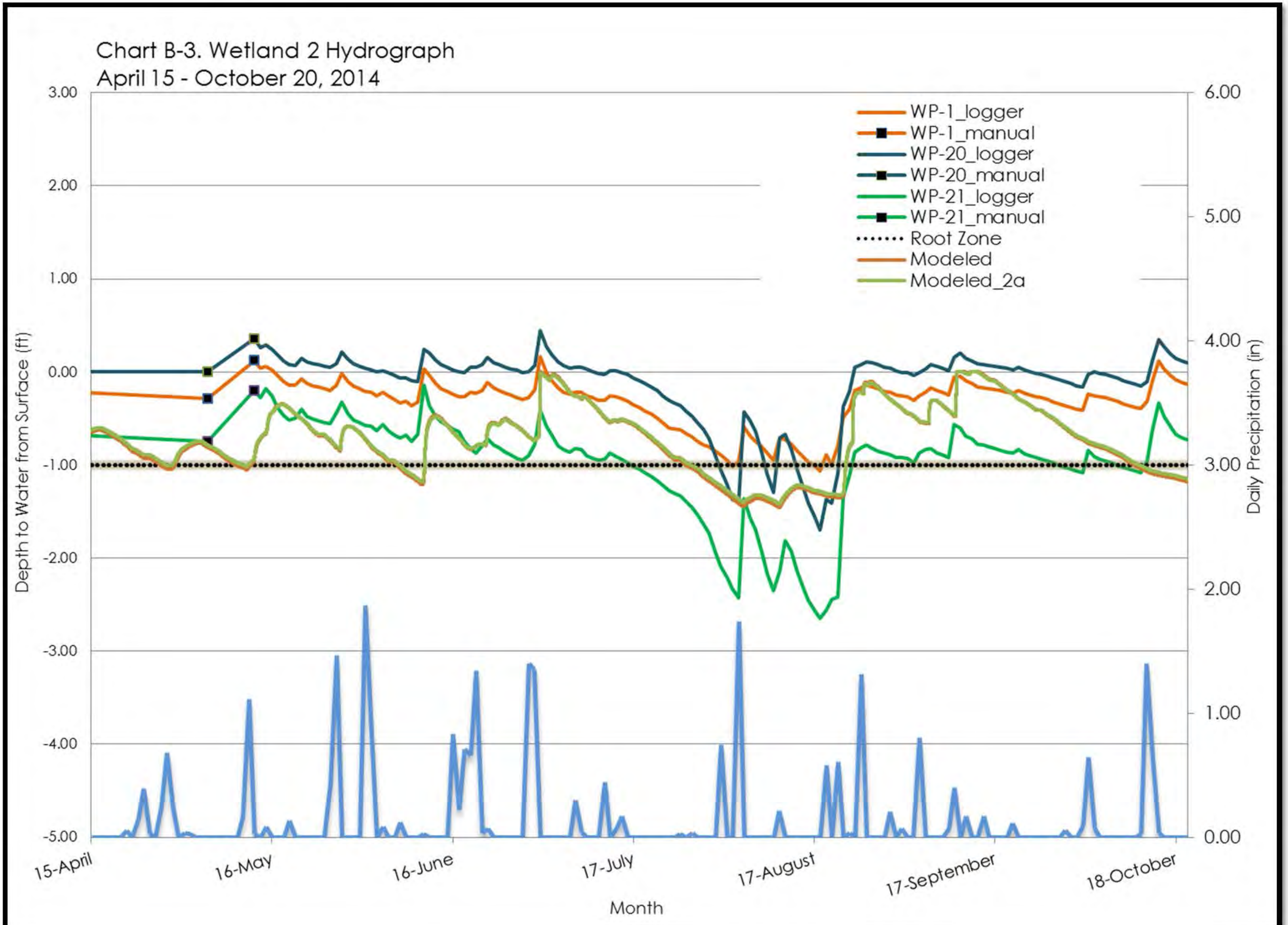


Chart B-3. Wetland 2 Hydrograph
April 15 - October 20, 2014
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
Depth to Water from Surface (ft)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Daily Precipitation (in)
WP-1_logger
WP-1_manual
WP-20_logger
WP-20_manual
WP-21_logger
WP-21_manual
Root Zone
Modeled
Modeled_2a
15-April
16-May
16-June
17-July
17-August
17-September
18-October
Month

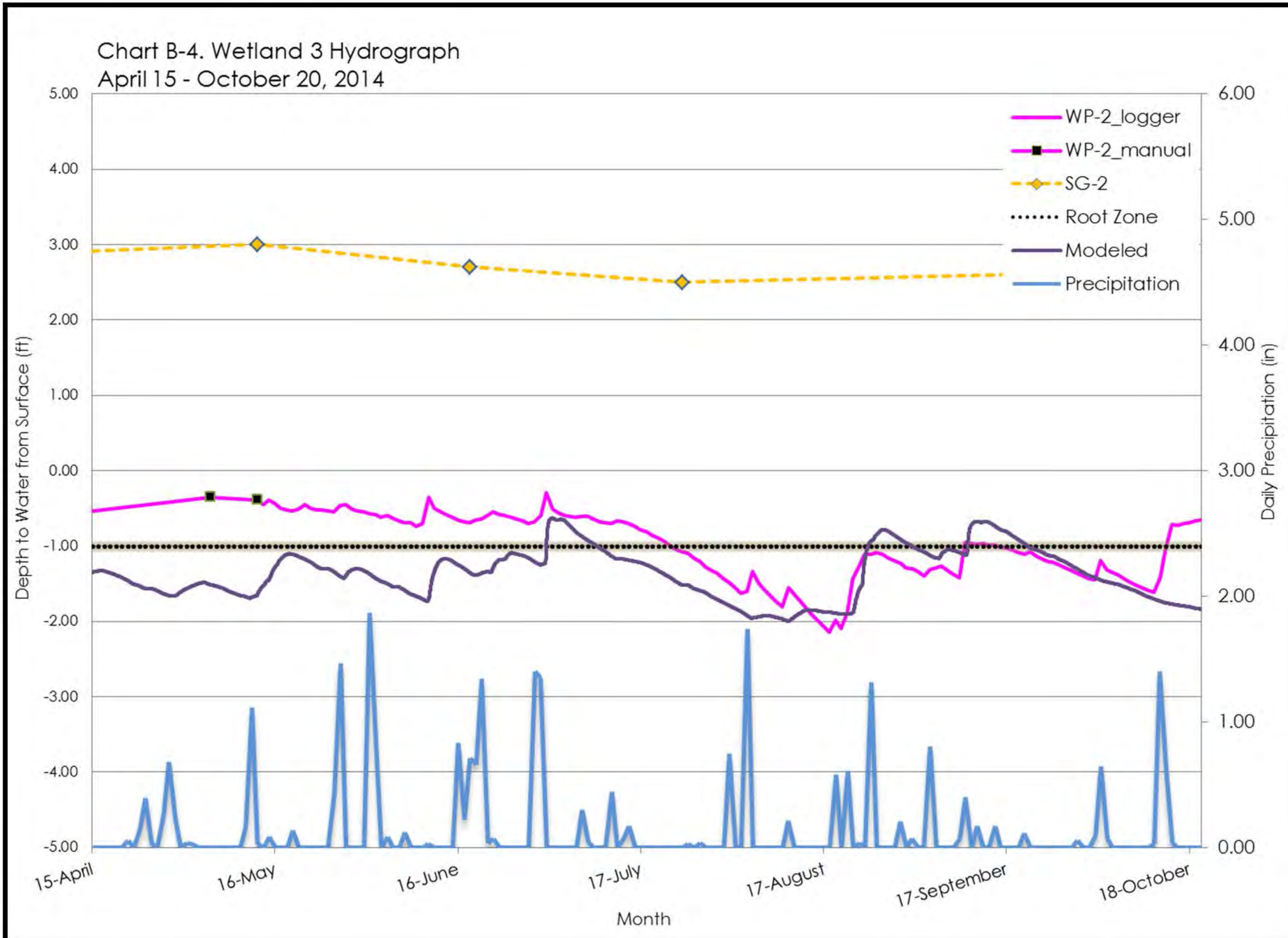


Chart B-4. Wetland 3 Hydrograph
April 15 - October 20, 2014
WP-2_logger
WP-2_manual
SG-2
Root Zone
Modeled
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
15-April
16-May
16-June
17-July
17-August
17-September
18-October
Month

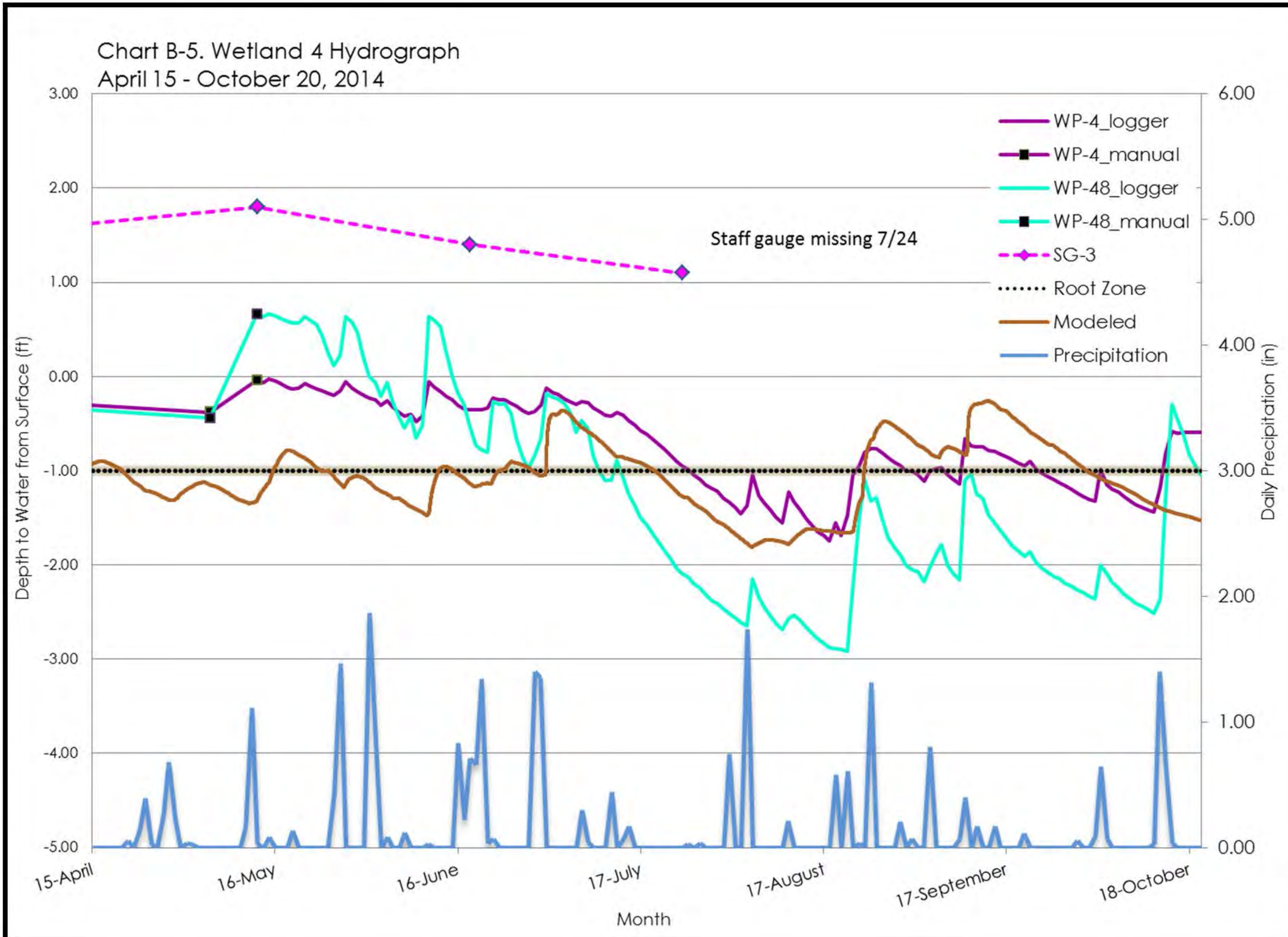


Chart B-5. Wetland 4 Hydrograph
April 15 - October 20, 2014
WP-4_logger
WP-4_manual
WP-48_logger
WP-48_manual
SG-3
Root Zone
Modeled
Precipitation
Staff gauge missing 7/24
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Depth to Water from Surface (ft)
Daily Precipitation (in)
15-April
16-May
16-June
17-July
17-August
17-September
18-October
Month

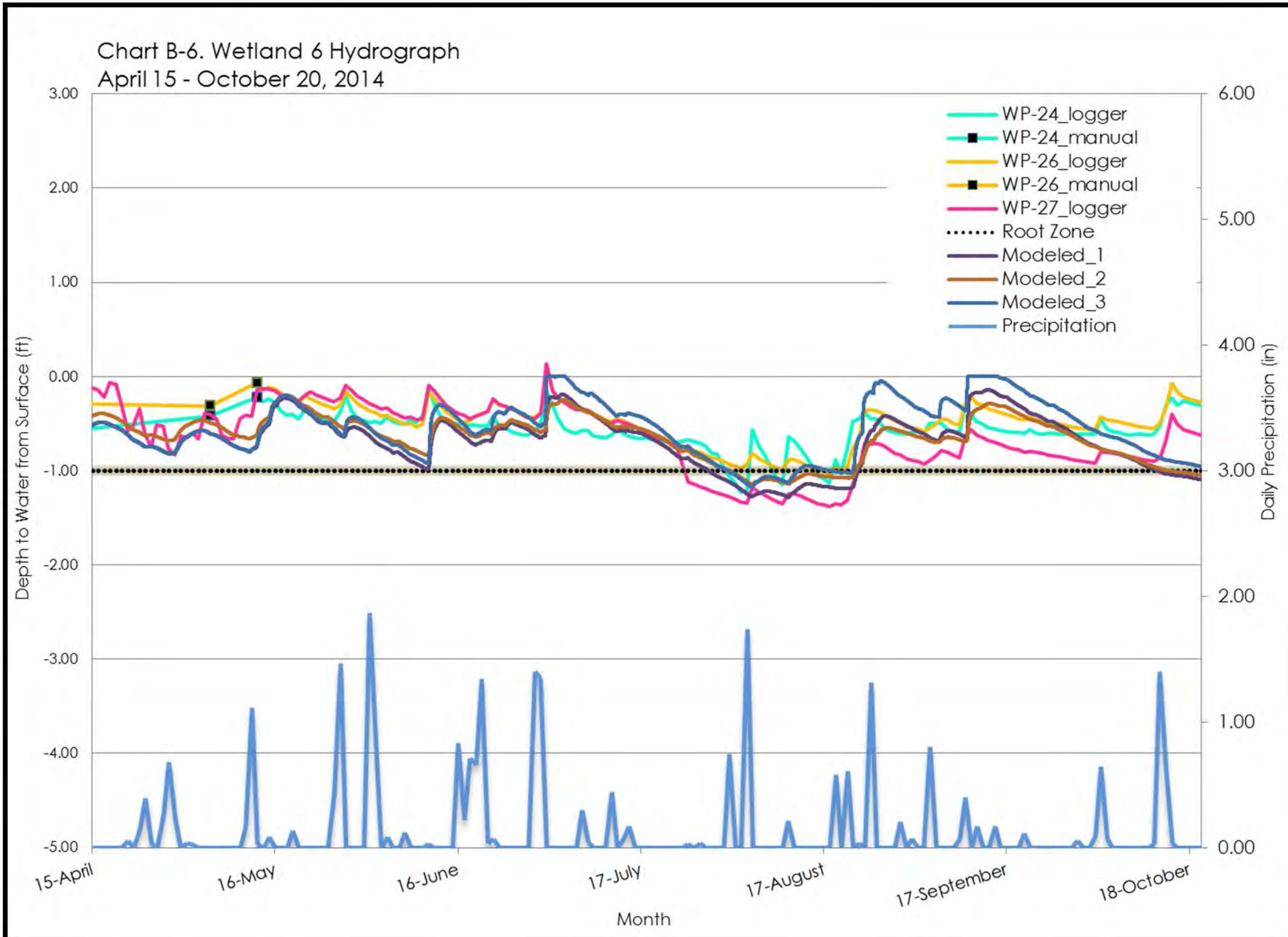


Chart B-6. Wetland 6 Hydrograph
April 15 - October 20, 2014
WP-24_logger
WP-24_manual
WP-26_logger
WP-26_manual
WP-27_logger
Root Zone
Modeled_1
Modeled_2
Modeled_3
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
15-April
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17-July
17-August
17-September
18-October
Month

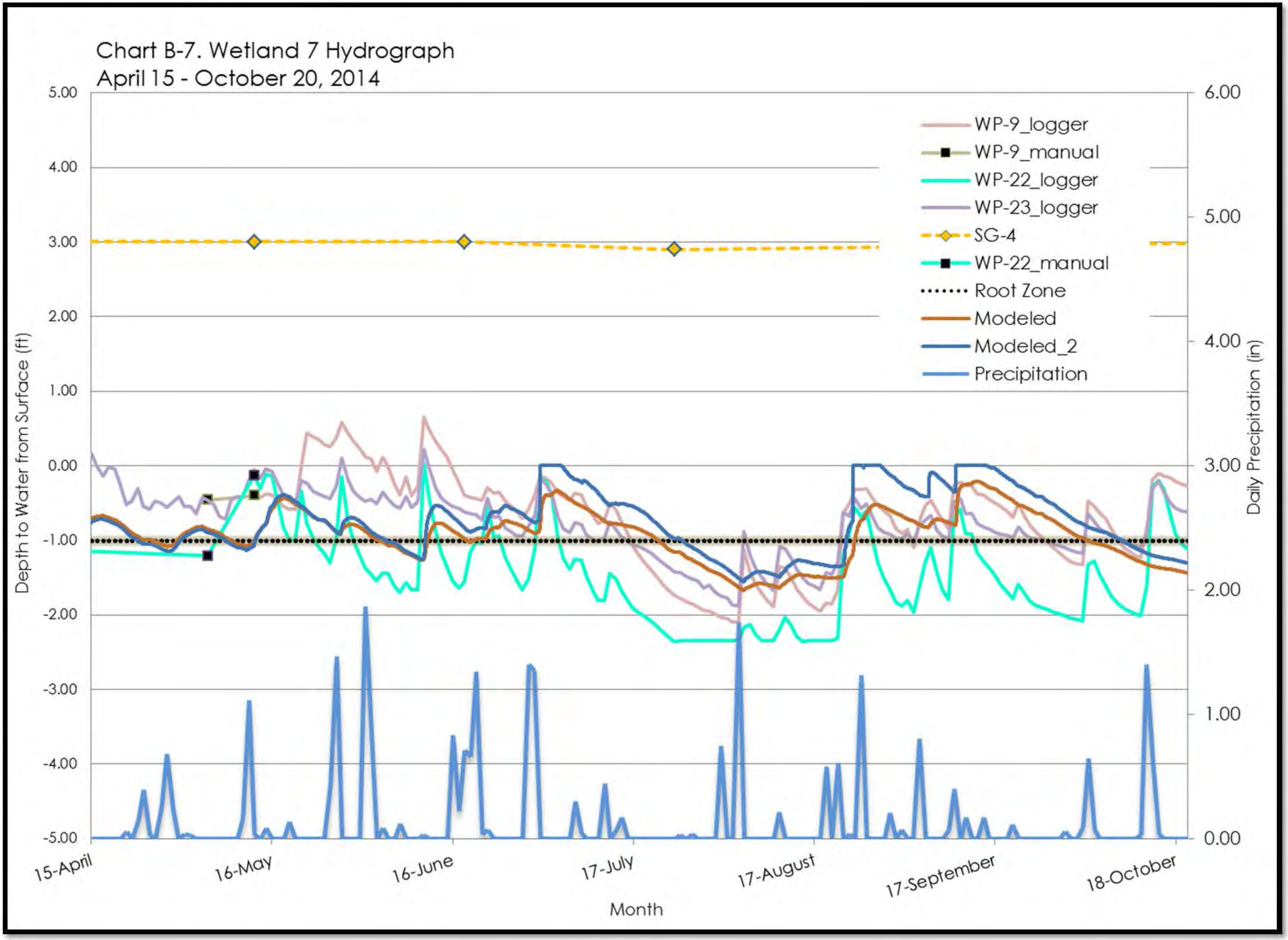
Chart B-7. Wetland 7 Hydrograph
April 15 - October 20, 2014
Depth to Water from Surface (ft)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
Daily Precipitation (in)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
WP-9_logger
WP-9_manual
WP-22_logger
WP-23_logger
SG-4
WP-22_manual
Root Zone
Modeled
Modeled_2
Precipitation
15-April
16-May
16-June
17-July
17-August
17-September
18-October
Month

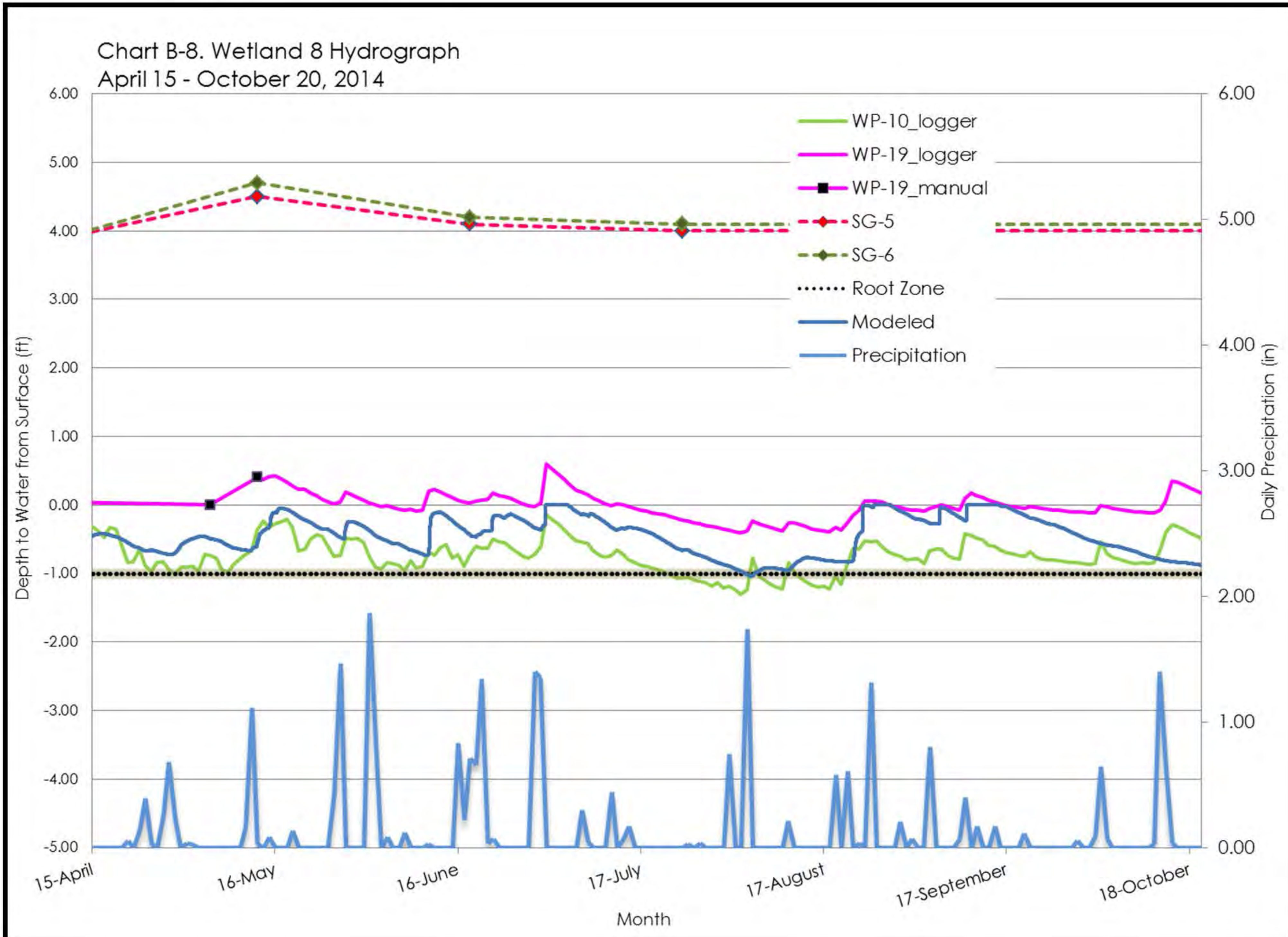
Chart B-8. Wetland 8 Hydrograph
April 15 - October 20, 2014
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
Depth to Water from Surface (ft)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Daily Precipitation (in)
WP-10_logger
WP-19_logger
WP-19_manual
SG-5
SG-6
Root Zone
Modeled
Precipitation
15-April
16-May
16-June
17-July
17-August
17-September
18-October
Month

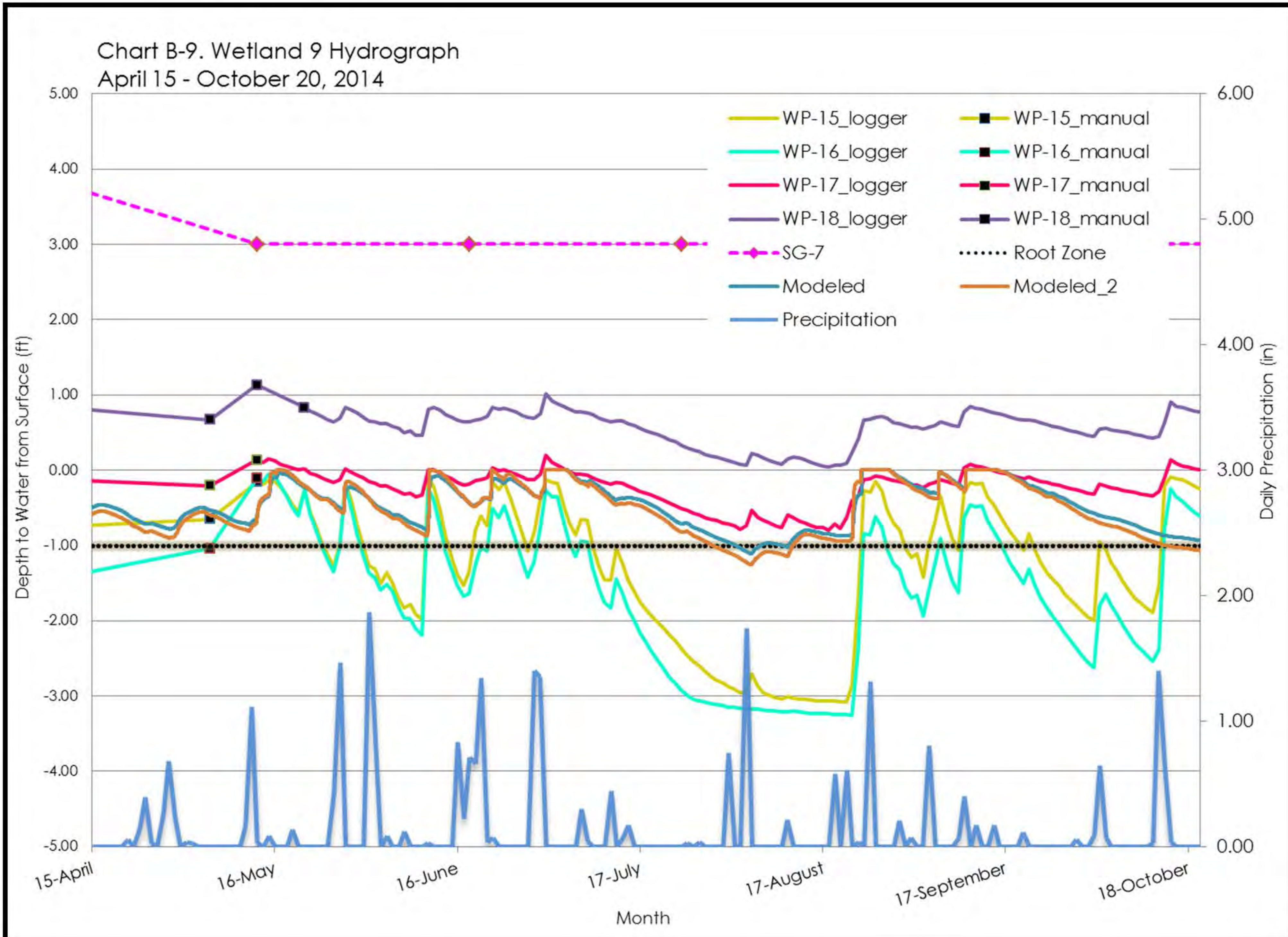
Chart B-9. Wetland 9 Hydrograph
April 15 - October 20, 2014
Depth to Water from Surface (ft)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
Daily Precipitation (in)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
WP-15_logger
WP-15_manual
WP-16_logger
WP-16_manual
WP-17_logger
WP-17_manual
WP-18_logger
WP-18_manual
SG-7
Root Zone
Modeled
Modeled_2
Precipitation
15-April
16-May
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17-July
17-August
17-September
18-October
Month

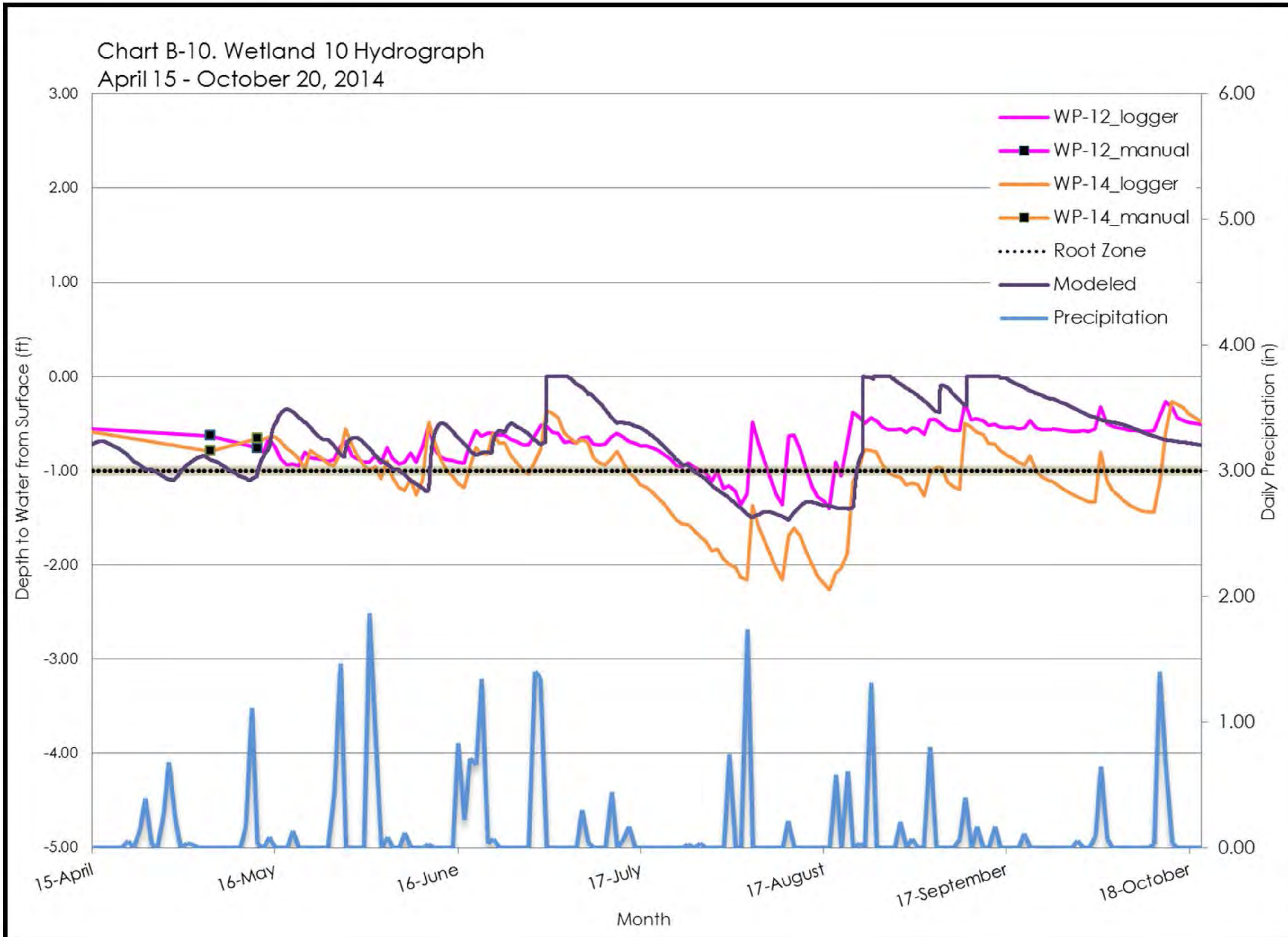


Chart B-10. Wetland 10 Hydrograph
April 15 - October 20, 2014
WP-12_logger
WP-12_manual
WP-14_logger
WP-14_manual
Root Zone
Modeled
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
15-April
16-May
16-June
17-July
17-August
17-September
18-October
Month

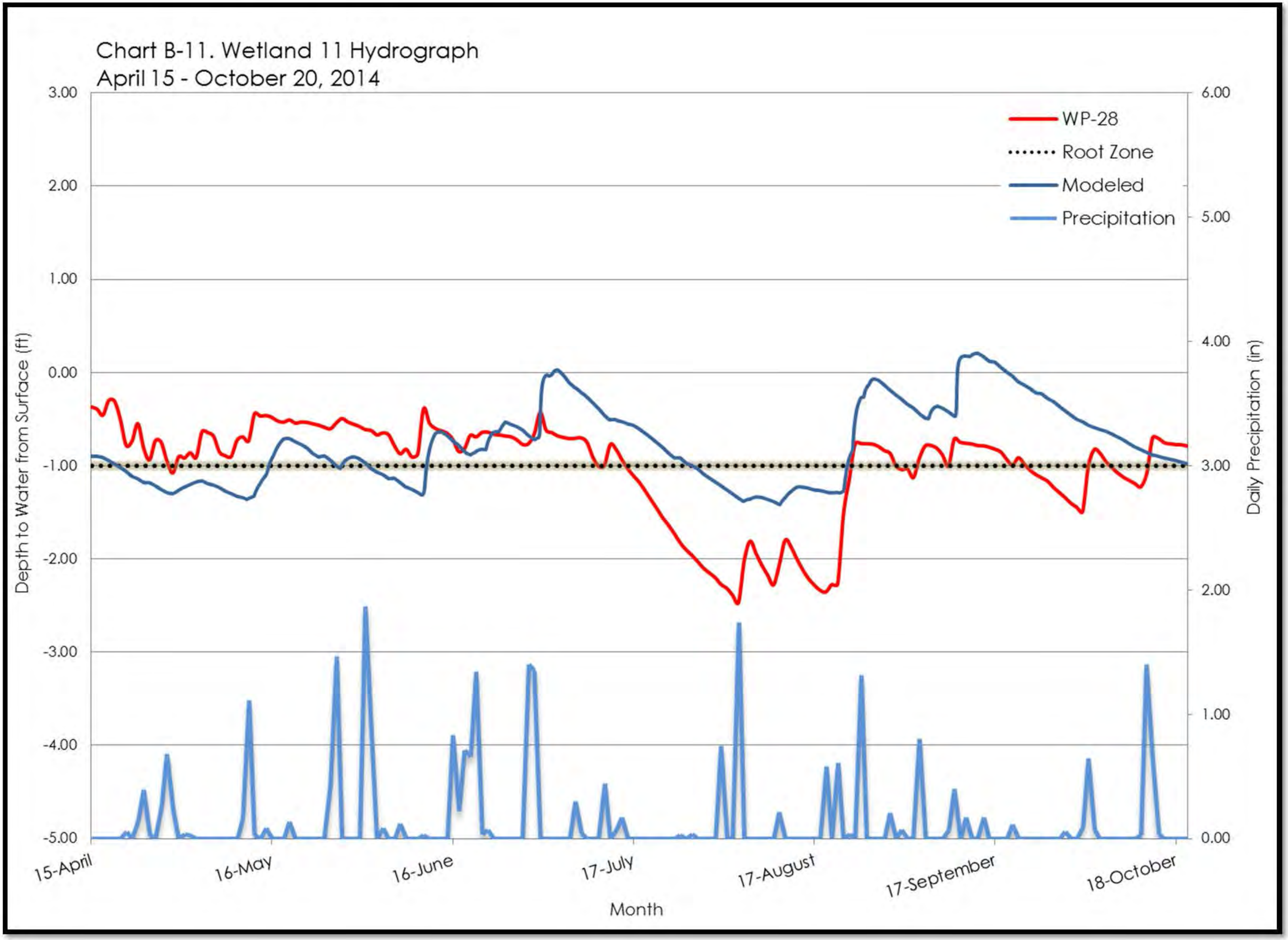


Chart B-11. Wetland 11 Hydrograph
April 15 - October 20, 2014
WP-28
Root Zone
Modeled
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
15-April
16-May
16-June
17-July
17-August
17-September
18-October
Month

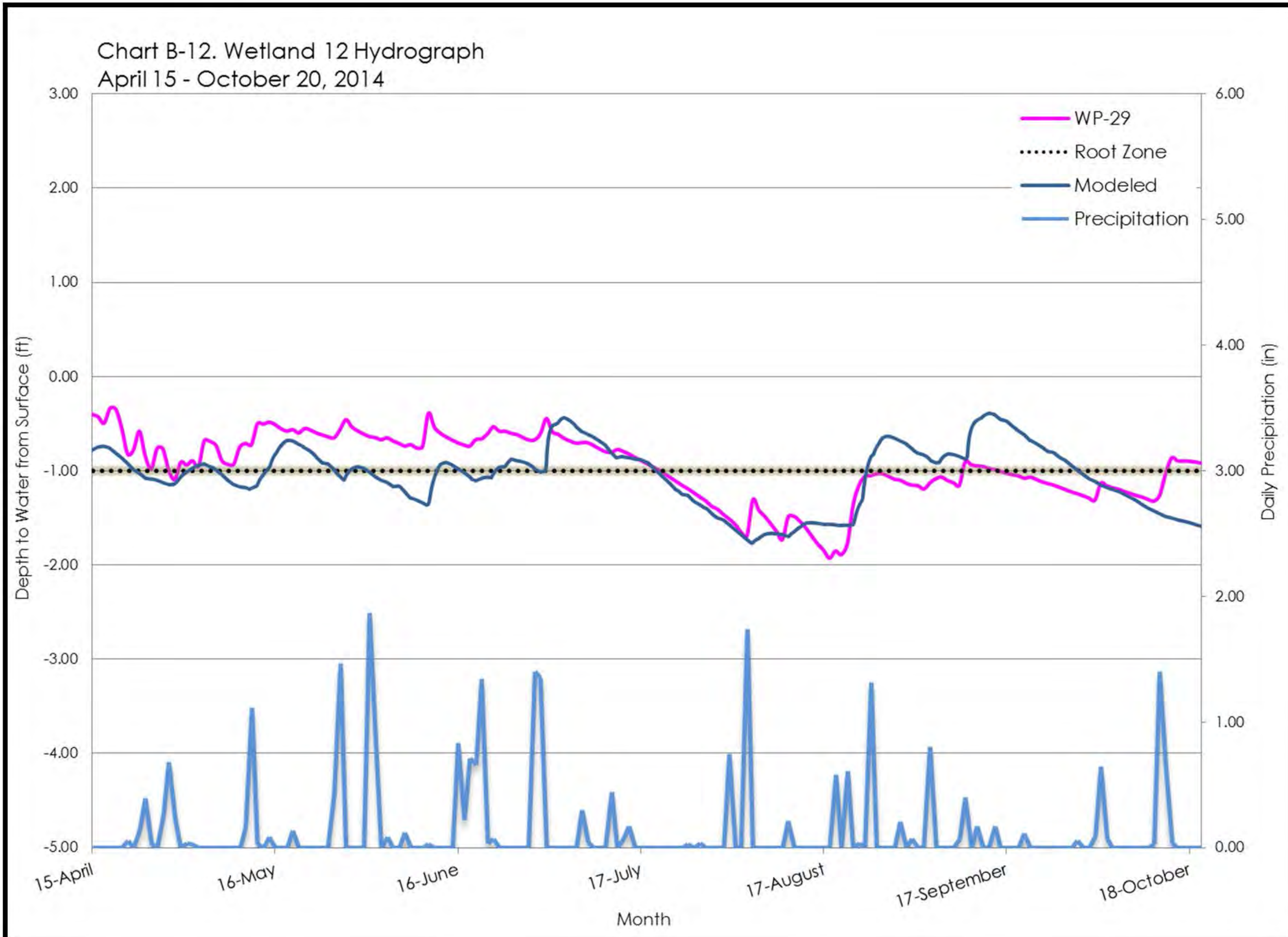


Chart B-12. Wetland 12 Hydrograph
April 15 - October 20, 2014
WP-29
Root Zone
Modeled
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
15-April
16-May
16-June
17-July
17-August
17-September
18-October
Month

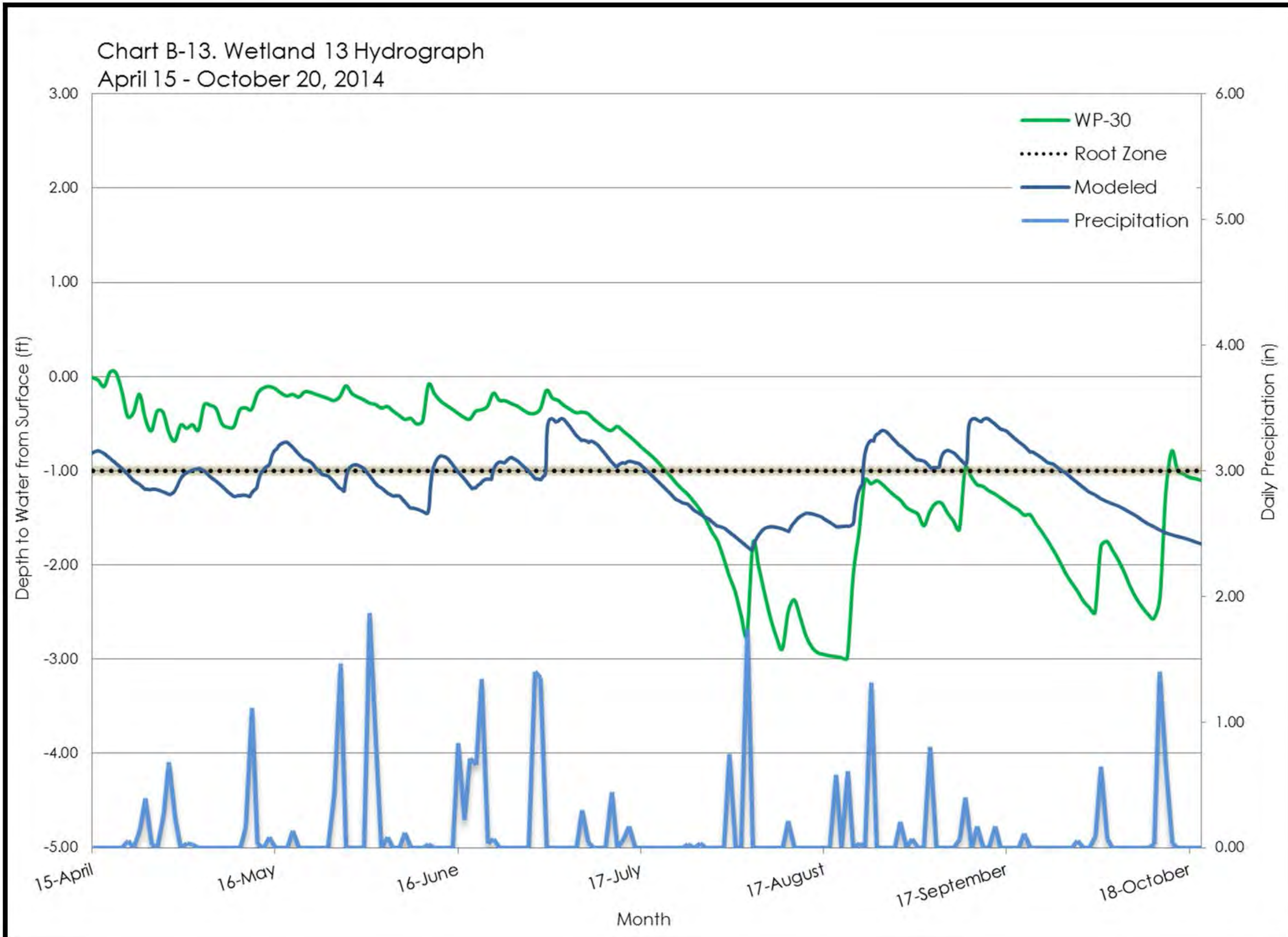
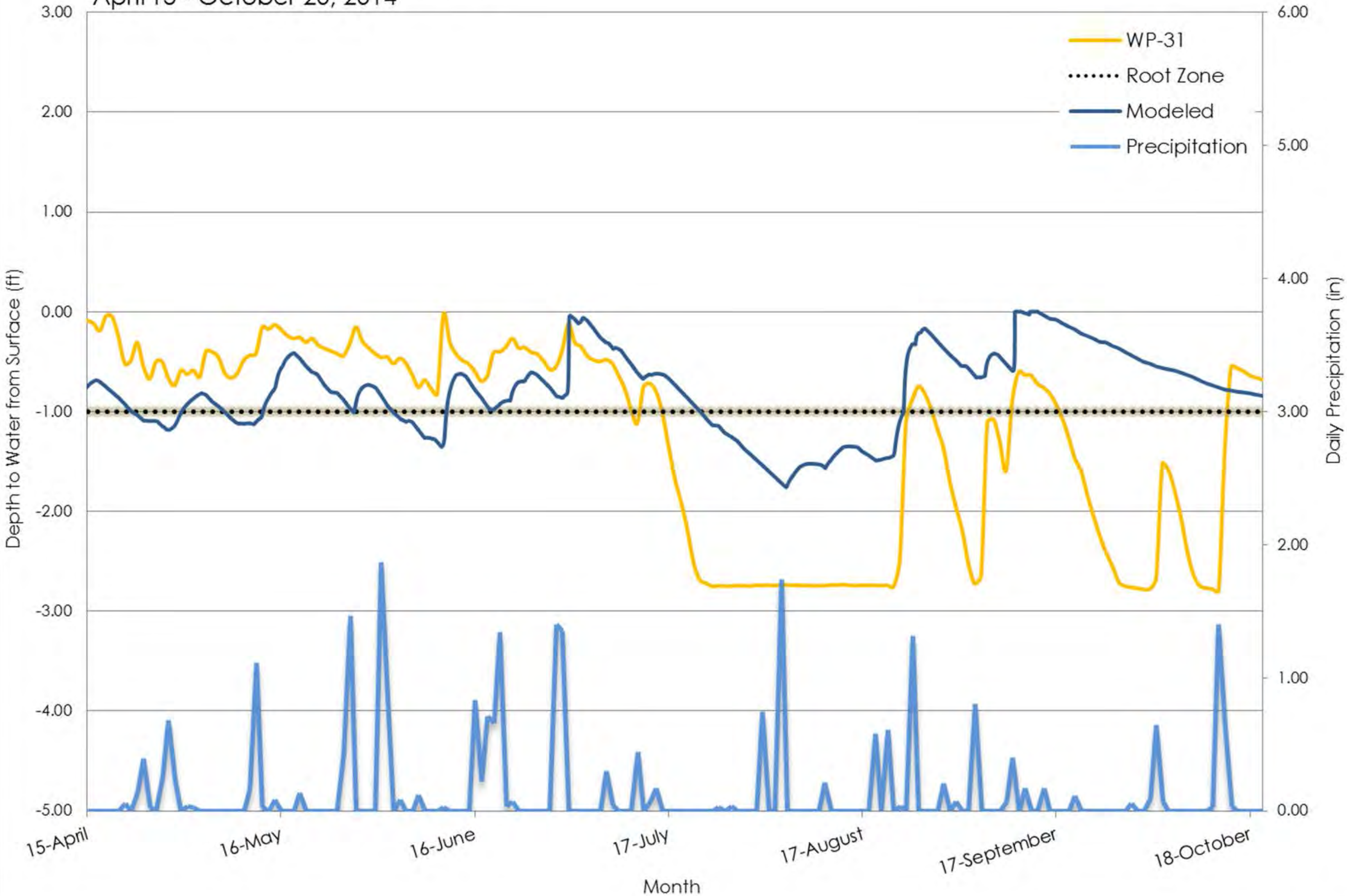


Chart B-13. Wetland 13 Hydrograph
April 15 - October 20, 2014
WP-30
Root Zone
Modeled
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
15-April
16-May
16-June
17-July
17-August
17-September
18-October
Month

Chart B-14. Wetland 14 Hydrograph
April 15 - October 20, 2014



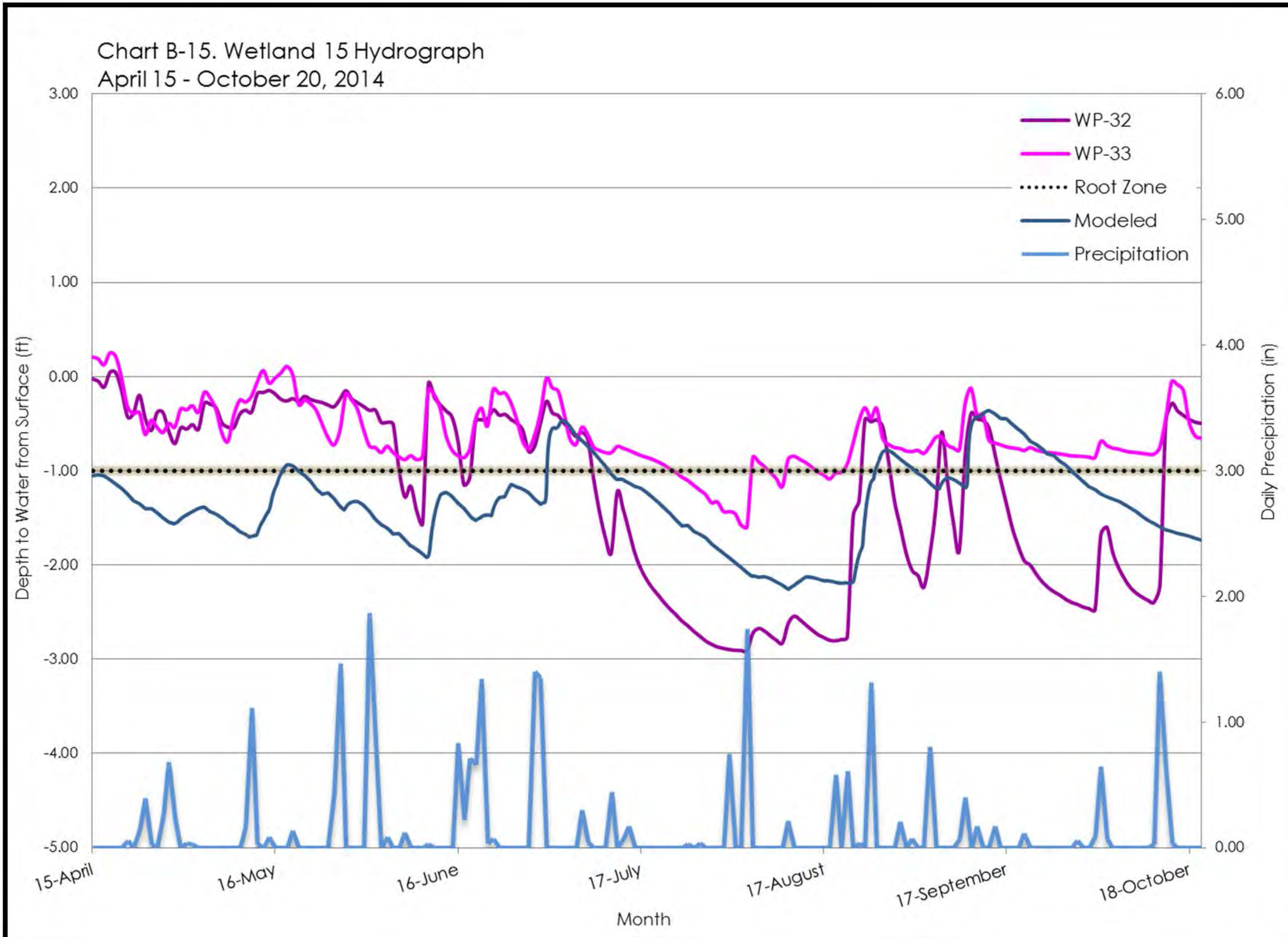


Chart B-15. Wetland 15 Hydrograph
April 15 - October 20, 2014
WP-32
WP-33
Root Zone
Modeled
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
15-April
16-May
16-June
17-July
17-August
17-September
18-October
Month

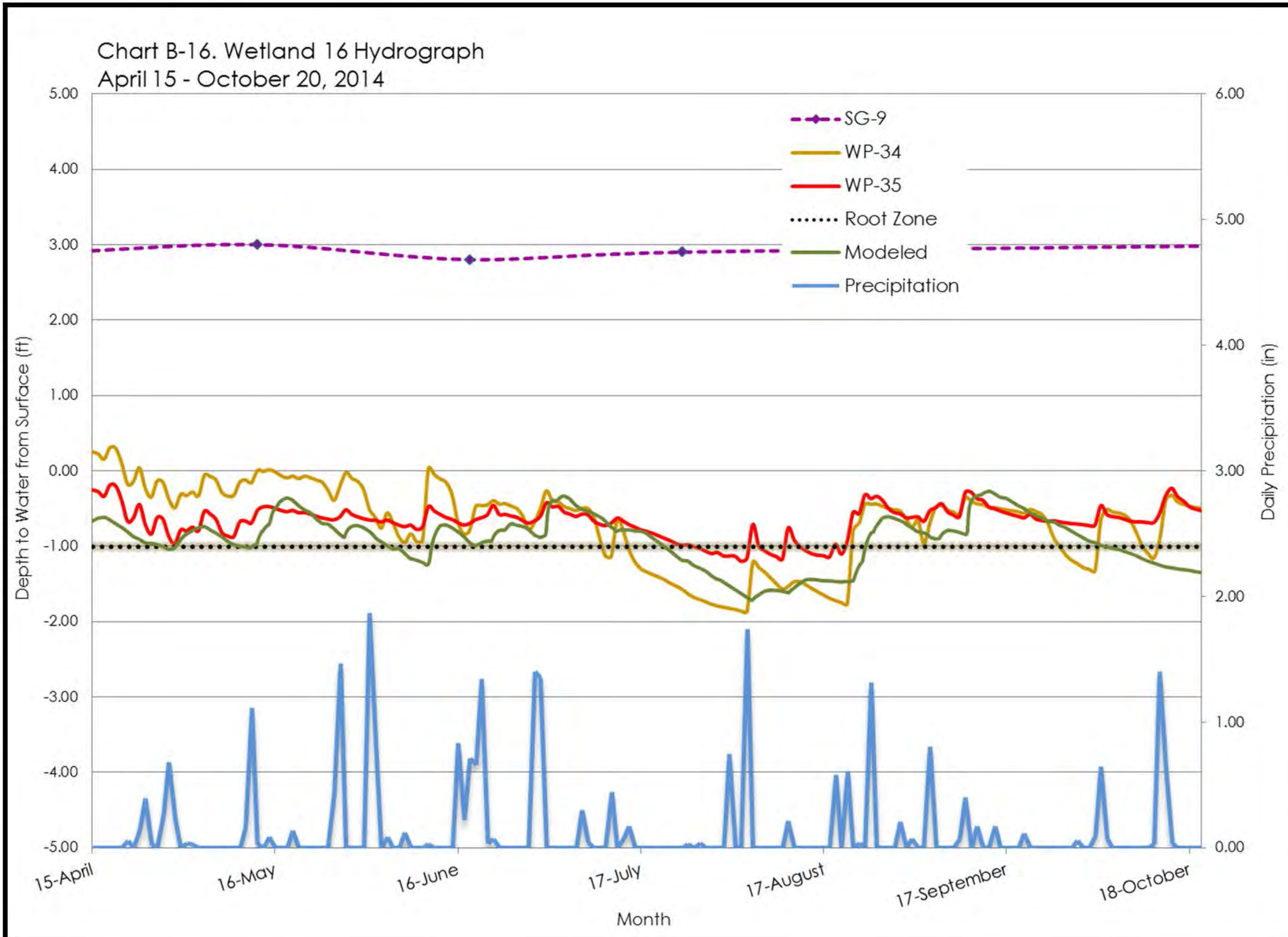


Chart B-16. Wetland 16 Hydrograph
April 15 - October 20, 2014
SG-9
WP-34
WP-35
Root Zone
Modeled
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
15-April
16-May
16-June
17-July
17-August
17-September
18-October
Month

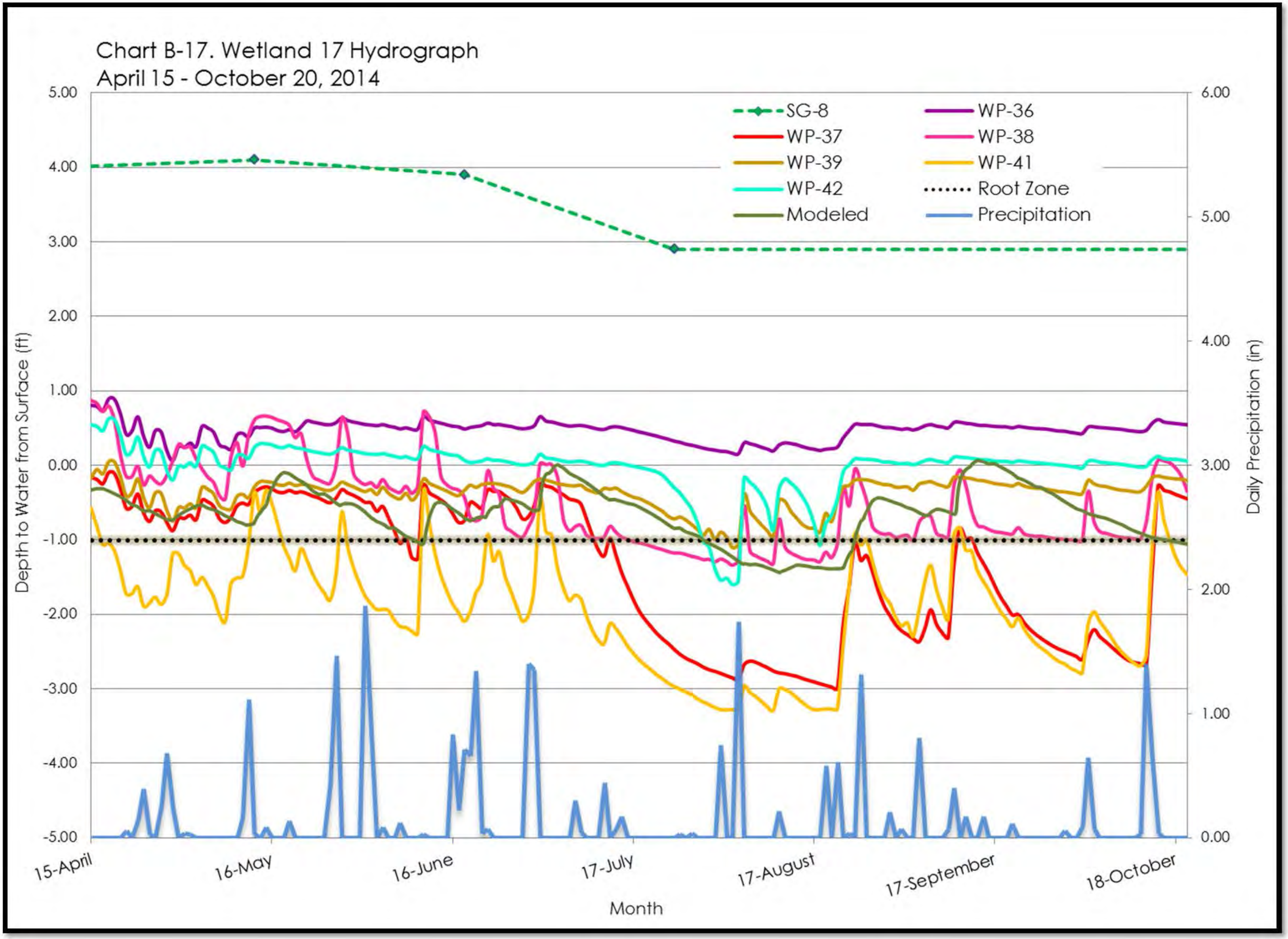


Chart B-17. Wetland 17 Hydrograph
April 15 - October 20, 2014
SG-8
WP-36
WP-37
WP-38
WP-39
WP-41
WP-42
Root Zone
Modeled
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
15-April
16-May
16-June
17-July
17-August
17-September
18-October
Month

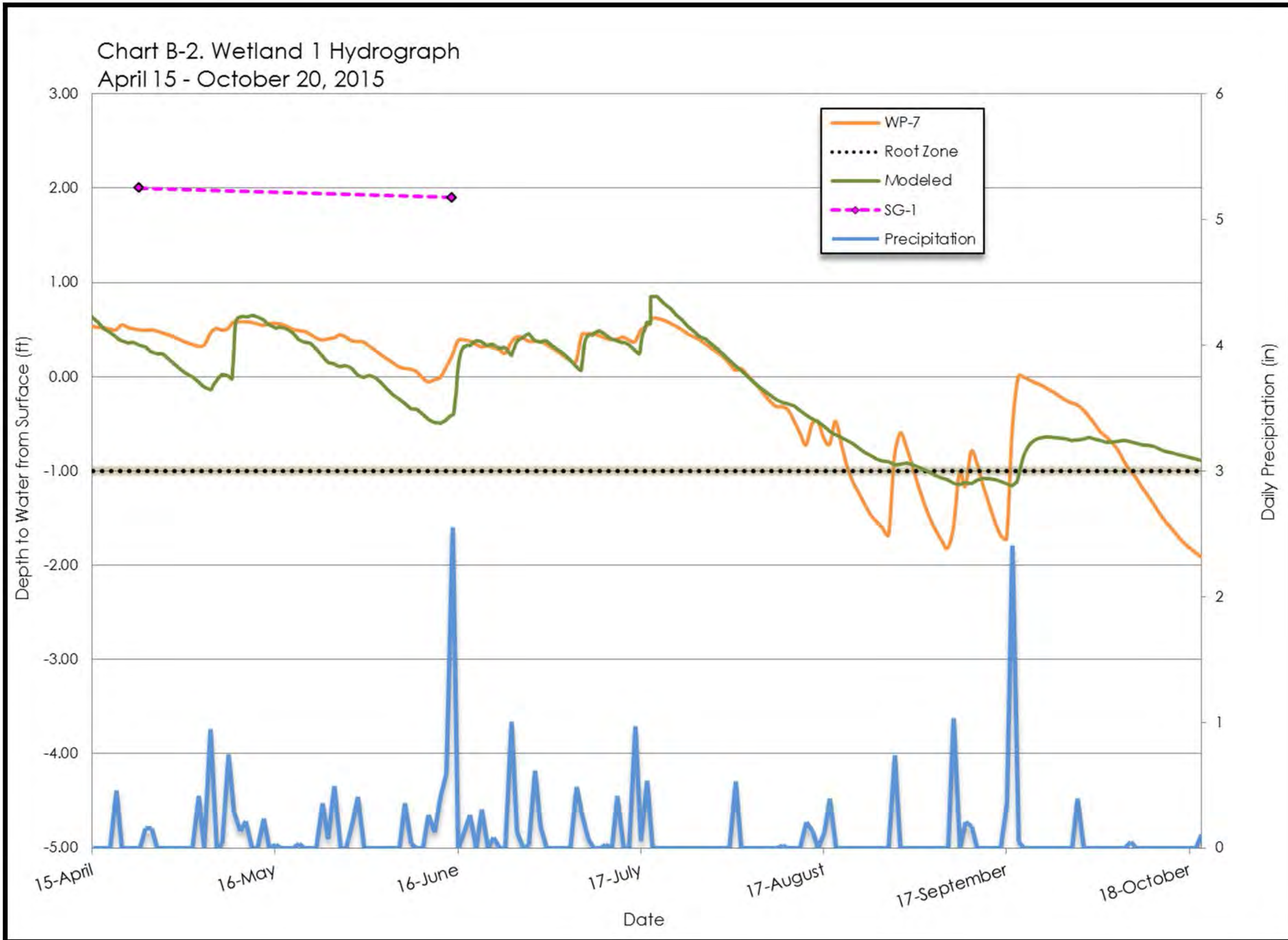


Chart B-2. Wetland 1 Hydrograph
April 15 - October 20, 2015
WP-7
Root Zone
Modeled
SG-1
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6
5
4
3
2
1
0
15-April
16-May
16-June
17-July
17-August
17-September
18-October
Date

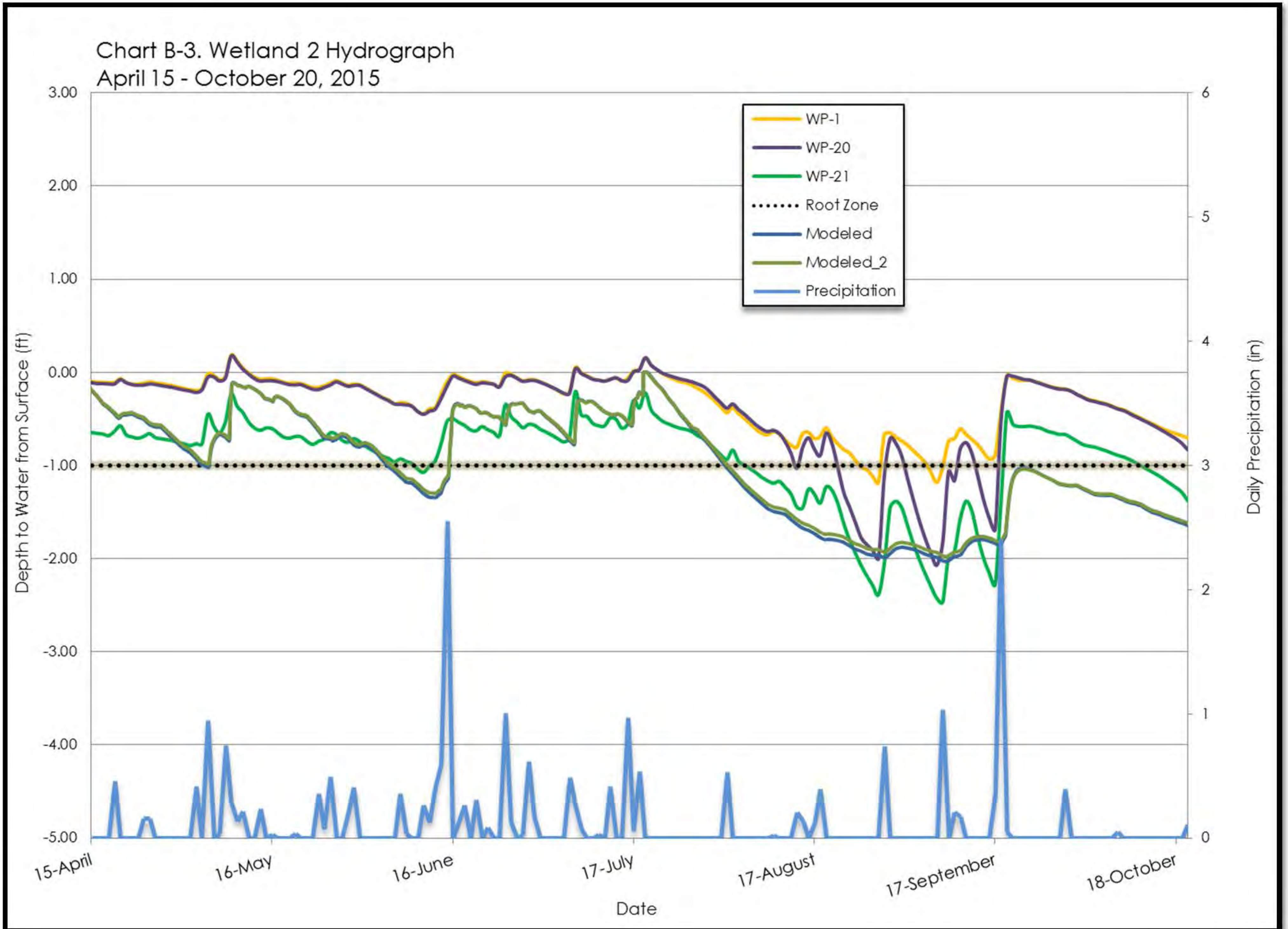


Chart B-3. Wetland 2 Hydrograph
April 15 - October 20, 2015
WP-1
WP-20
WP-21
Root Zone
Modeled
Modeled_2
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6
5
4
3
2
1
0
15-April
16-May
16-June
17-July
17-August
17-September
18-October
Date

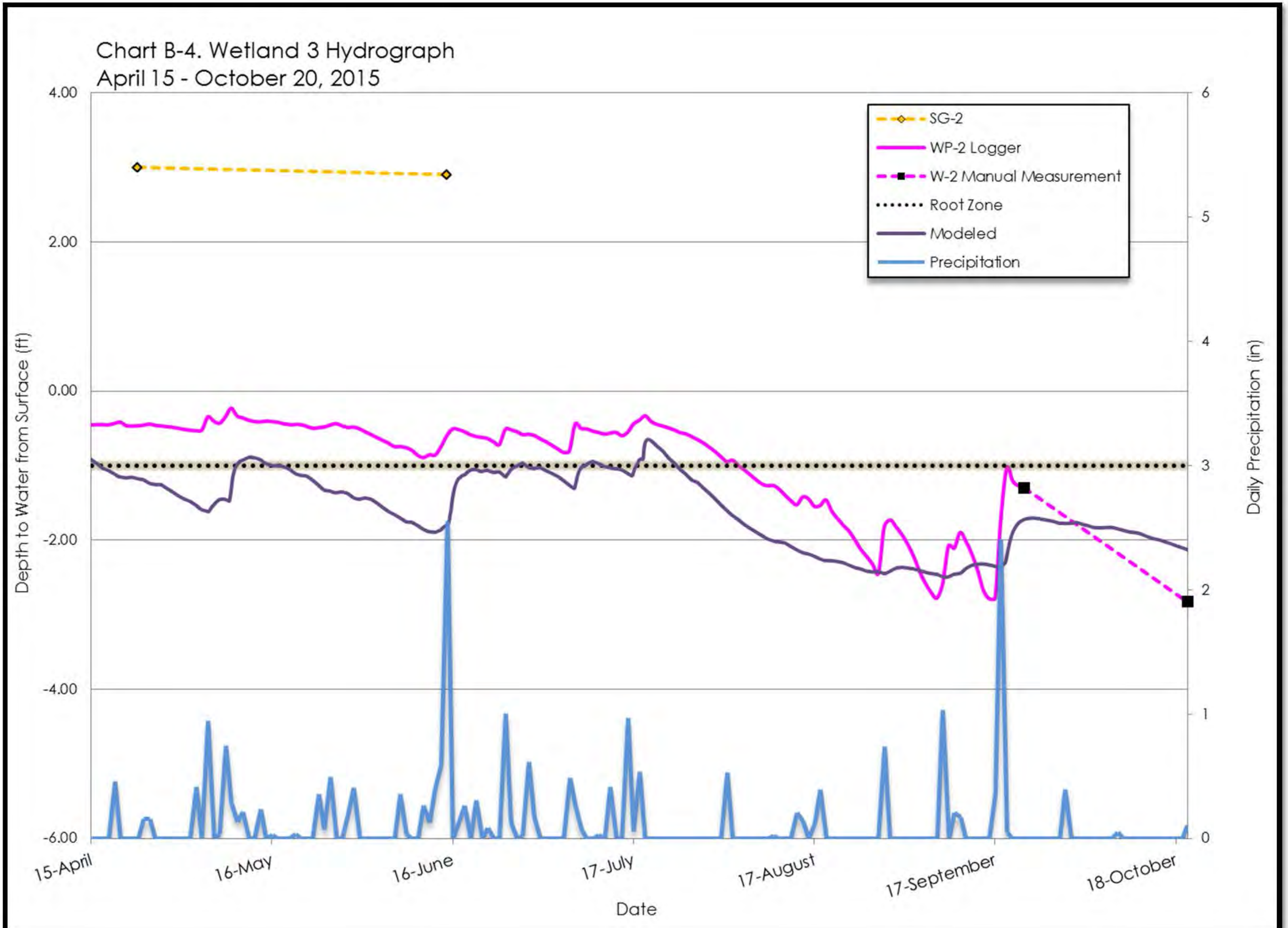


Chart B-4. Wetland 3 Hydrograph
April 15 - October 20, 2015
SG-2
WP-2 Logger
W-2 Manual Measurement
Root Zone
Modeled
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
4.00
2.00
0.00
-2.00
-4.00
-6.00
6
5
4
3
2
1
0
15-April
16-May
16-June
17-July
17-August
17-September
18-October
Date

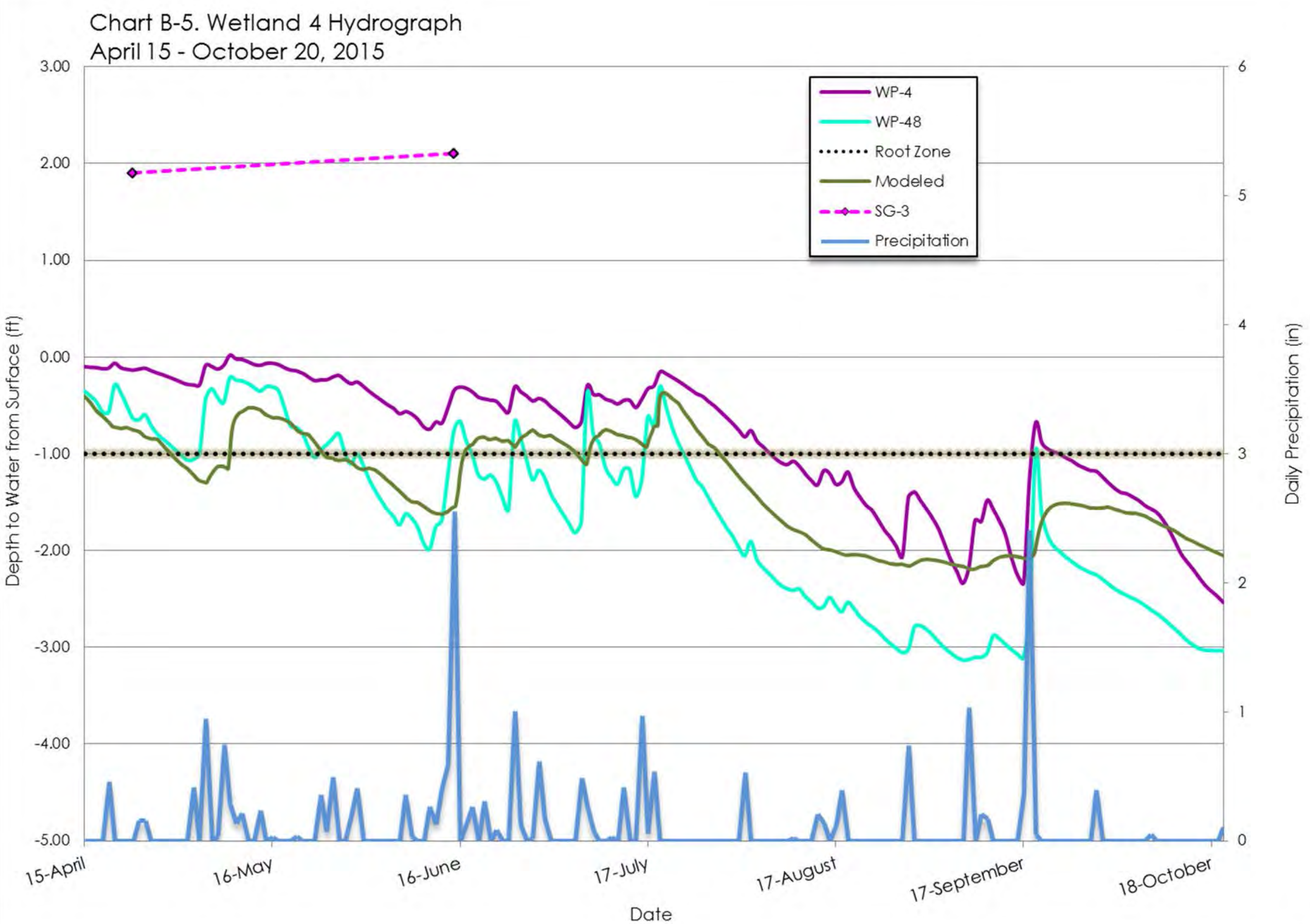


Chart B-5. Wetland 4 Hydrograph
April 15 - October 20, 2015
Depth to Water from Surface (ft)
Daily Precipitation (in)
Date
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6
5
4
3
2
1
0
15-April
16-May
16-June
17-July
17-August
17-September
18-October
WP-4
WP-48
Root Zone
Modeled
SG-3
Precipitation

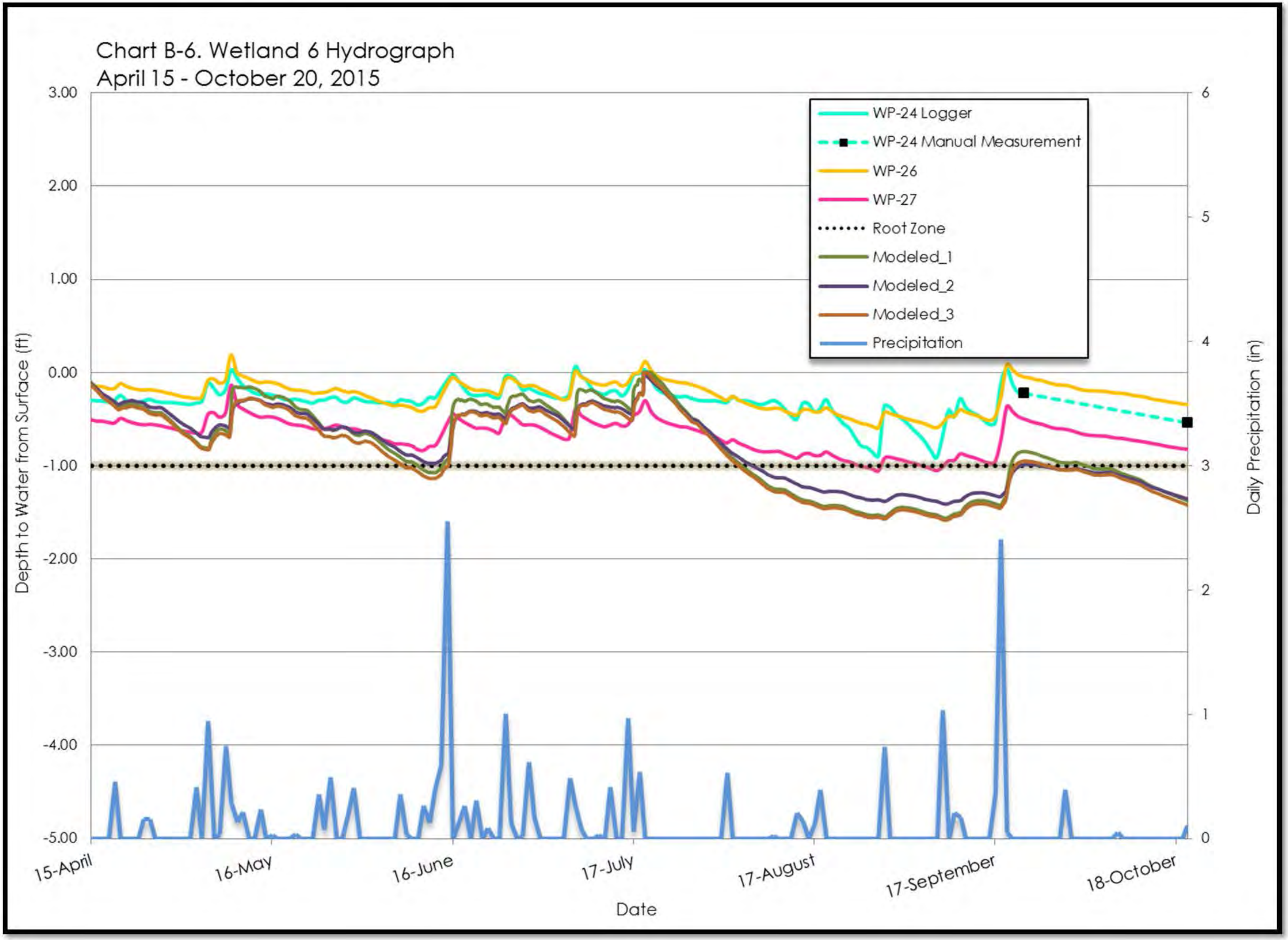


Chart B-6. Wetland 6 Hydrograph
April 15 - October 20, 2015
WP-24 Logger
WP-24 Manual Measurement
WP-26
WP-27
Root Zone
Modeled_1
Modeled_2
Modeled_3
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6
5
4
3
2
1
0
15-April
16-May
16-June
17-July
17-August
17-September
18-October
Date

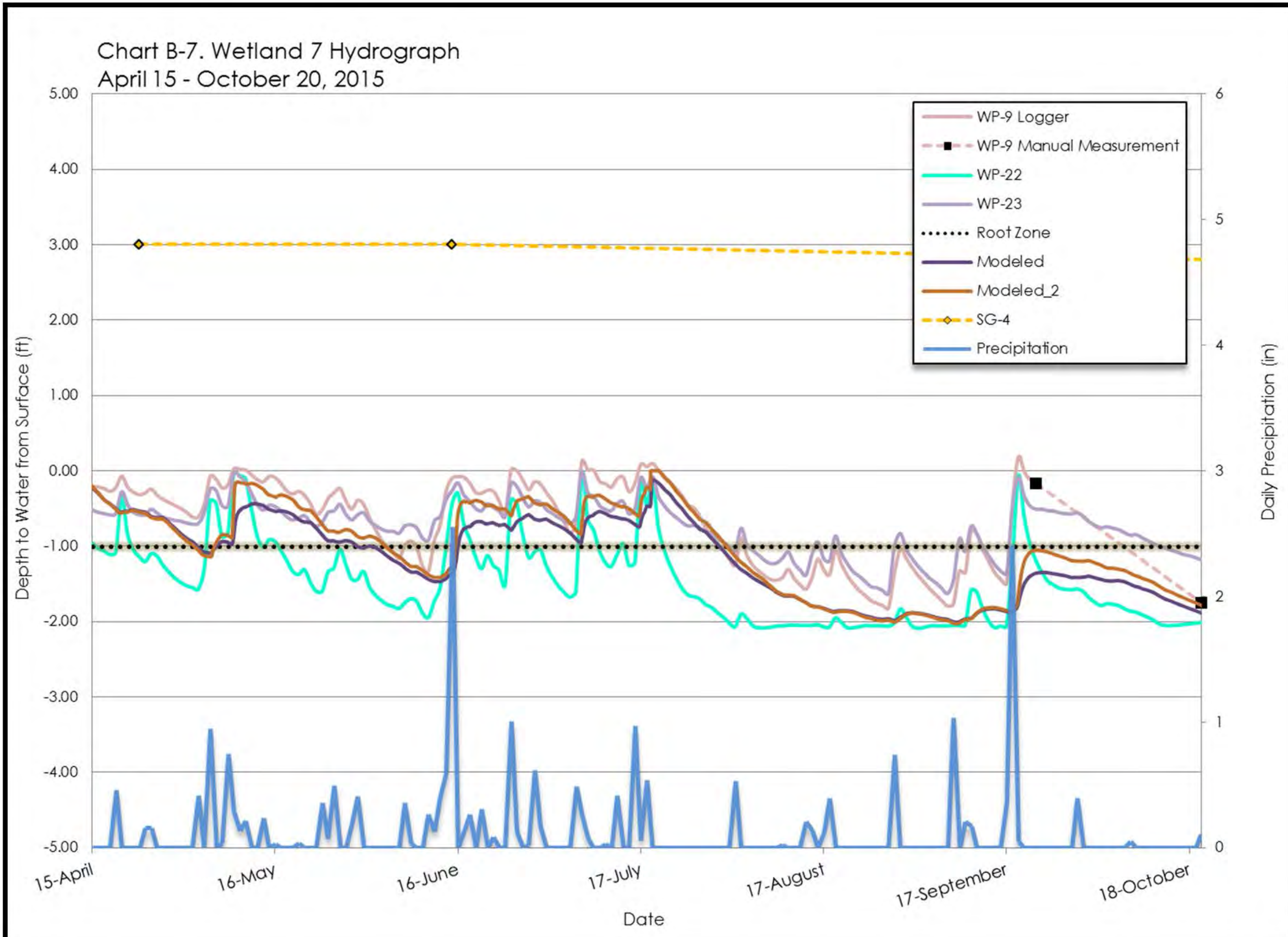


Chart B-7. Wetland 7 Hydrograph
April 15 - October 20, 2015
Depth to Water from Surface (ft)
Daily Precipitation (in)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6
5
4
3
2
1
0
WP-9 Logger
WP-9 Manual Measurement
WP-22
WP-23
Root Zone
Modeled
Modeled_2
SG-4
Precipitation
15-April
16-May
16-June
17-July
17-August
17-September
18-October
Date

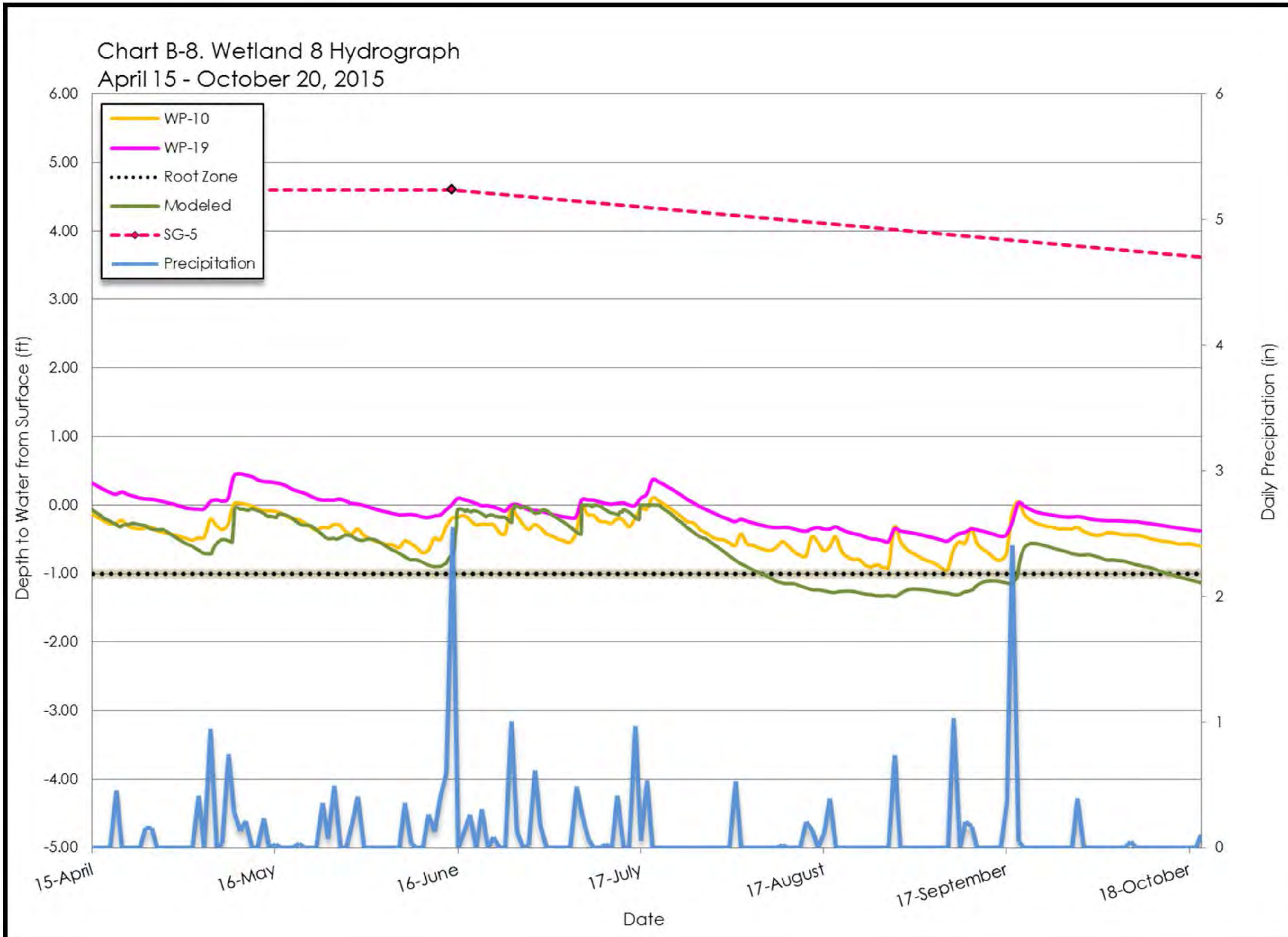


Chart B-8. Wetland 8 Hydrograph
April 15 - October 20, 2015
WP-10
WP-19
Root Zone
Modeled
SG-5
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6
5
4
3
2
1
0
15-April
16-May
16-June
17-July
17-August
17-September
18-October
Date

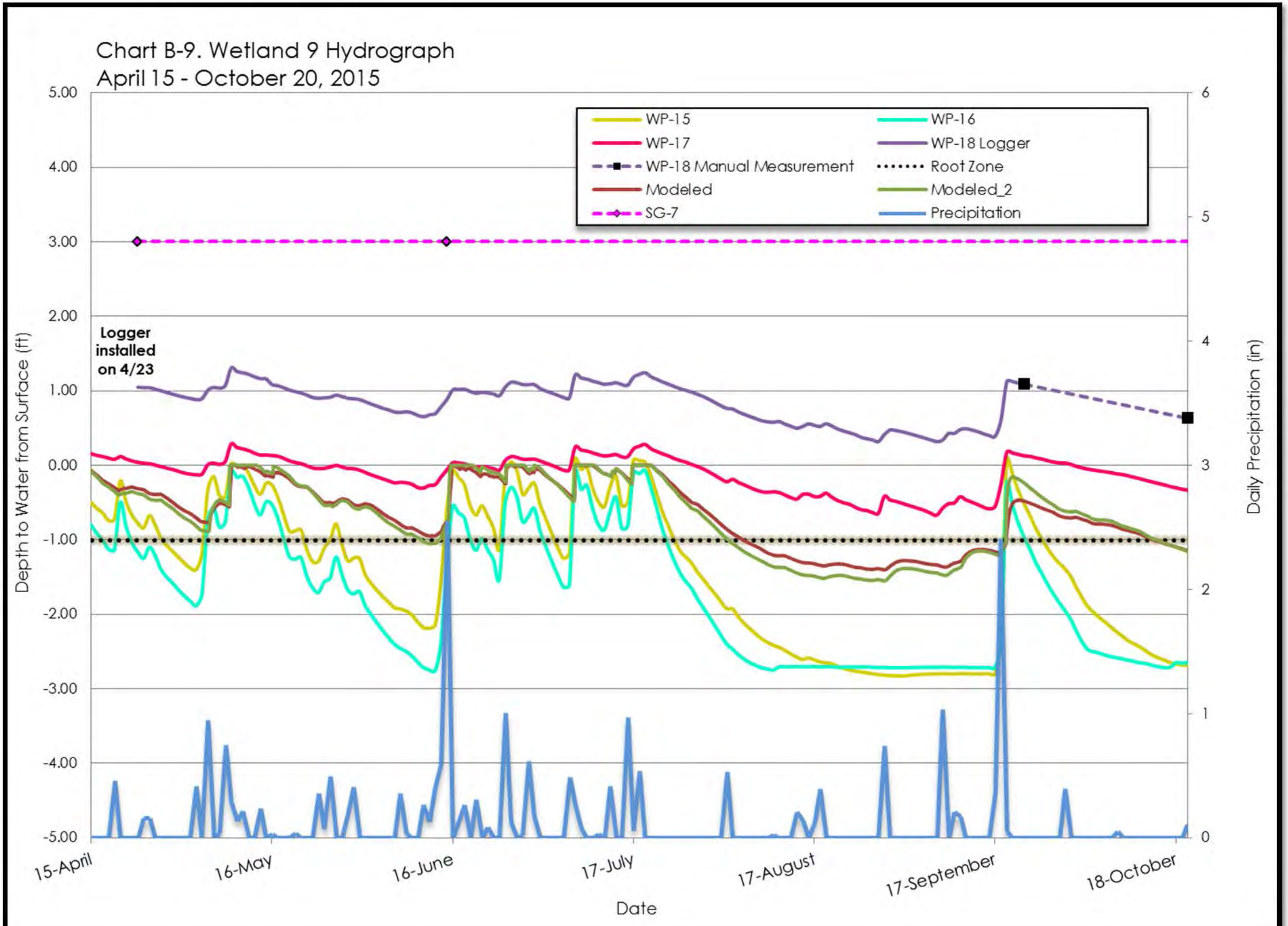


Chart B-9. Wetland 9 Hydrograph
April 15 - October 20, 2015
WP-15
WP-16
WP-17
WP-18 Logger
WP-18 Manual Measurement
Root Zone
Modeled
Modeled_2
SG-7
Precipitation
Logger installed on 4/23
Depth to Water from Surface (ft)
Daily Precipitation (in)
Date
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6
5
4
3
2
1
0
15-April
16-May
16-June
17-July
17-August
17-September
18-October

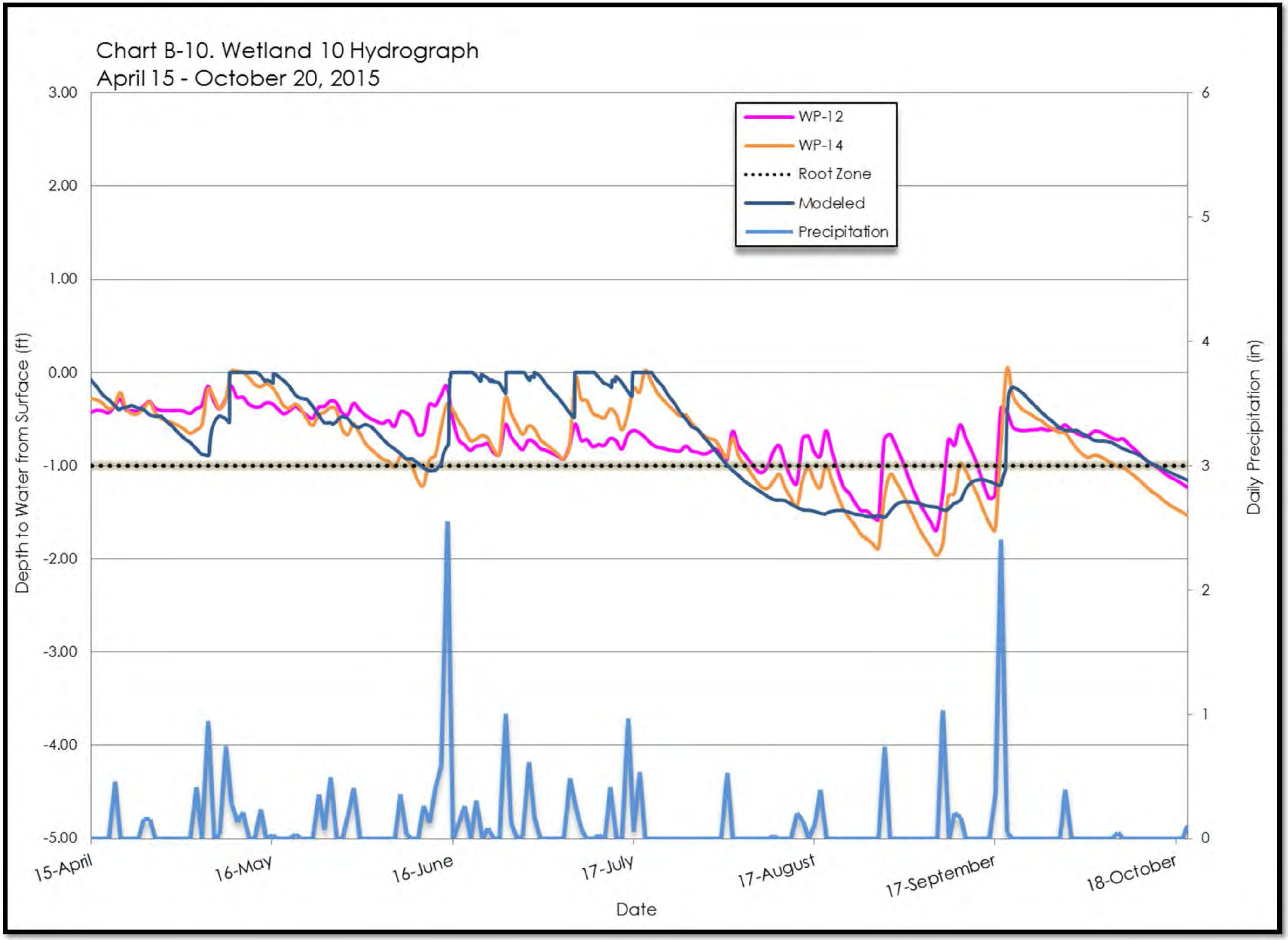


Chart B-10. Wetland 10 Hydrograph
April 15 - October 20, 2015
WP-12
WP-14
Root Zone
Modeled
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6
5
4
3
2
1
0
15-April
16-May
16-June
17-July
17-August
17-September
18-October
Date

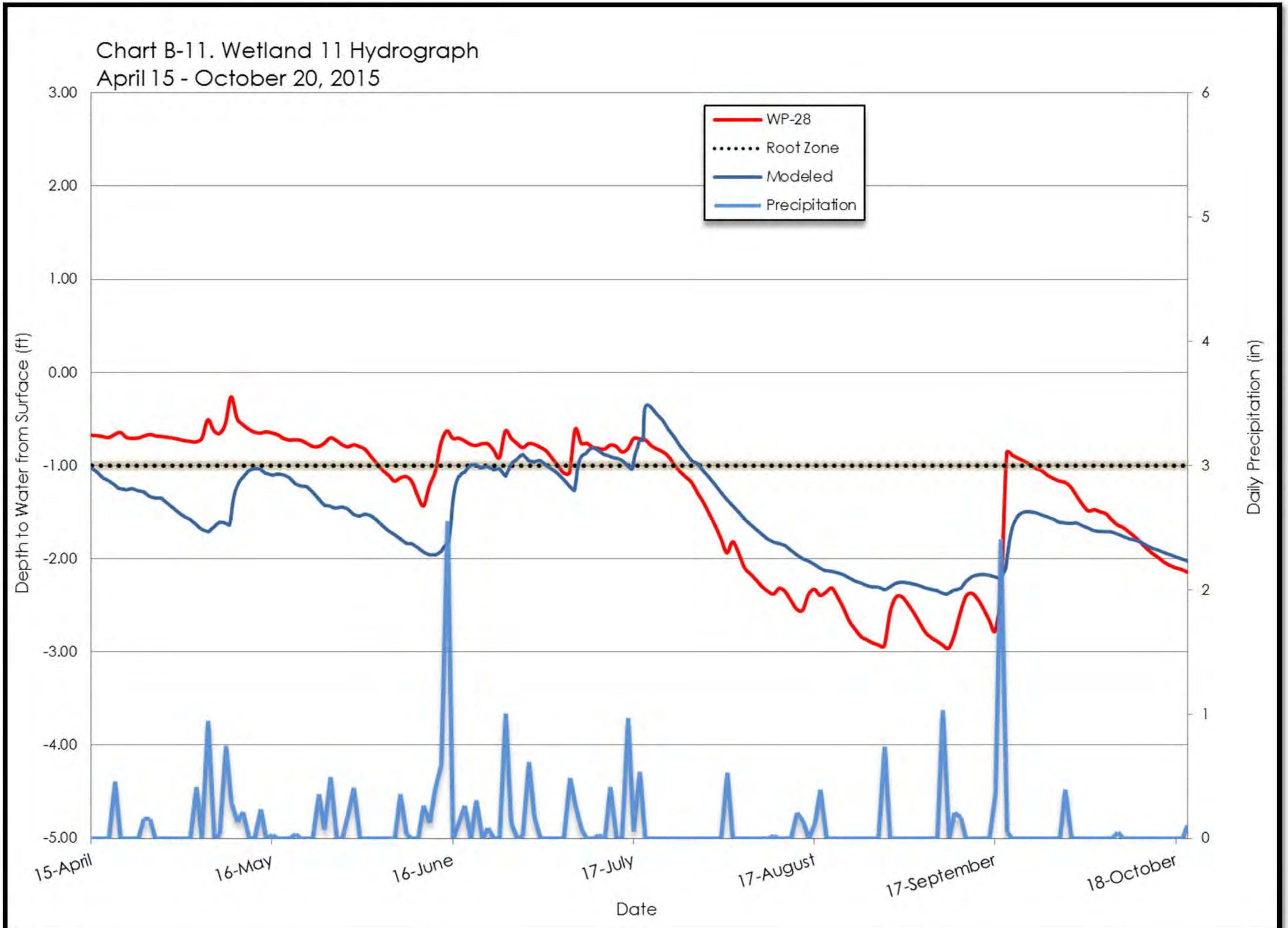


Chart B-11. Wetland 11 Hydrograph
April 15 - October 20, 2015
WP-28
Root Zone
Modeled
Precipitation
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6
5
4
3
2
1
0
Depth to Water from Surface (ft)
Daily Precipitation (in)
15-April
16-May
16-June
17-July
17-August
17-September
18-October
Date

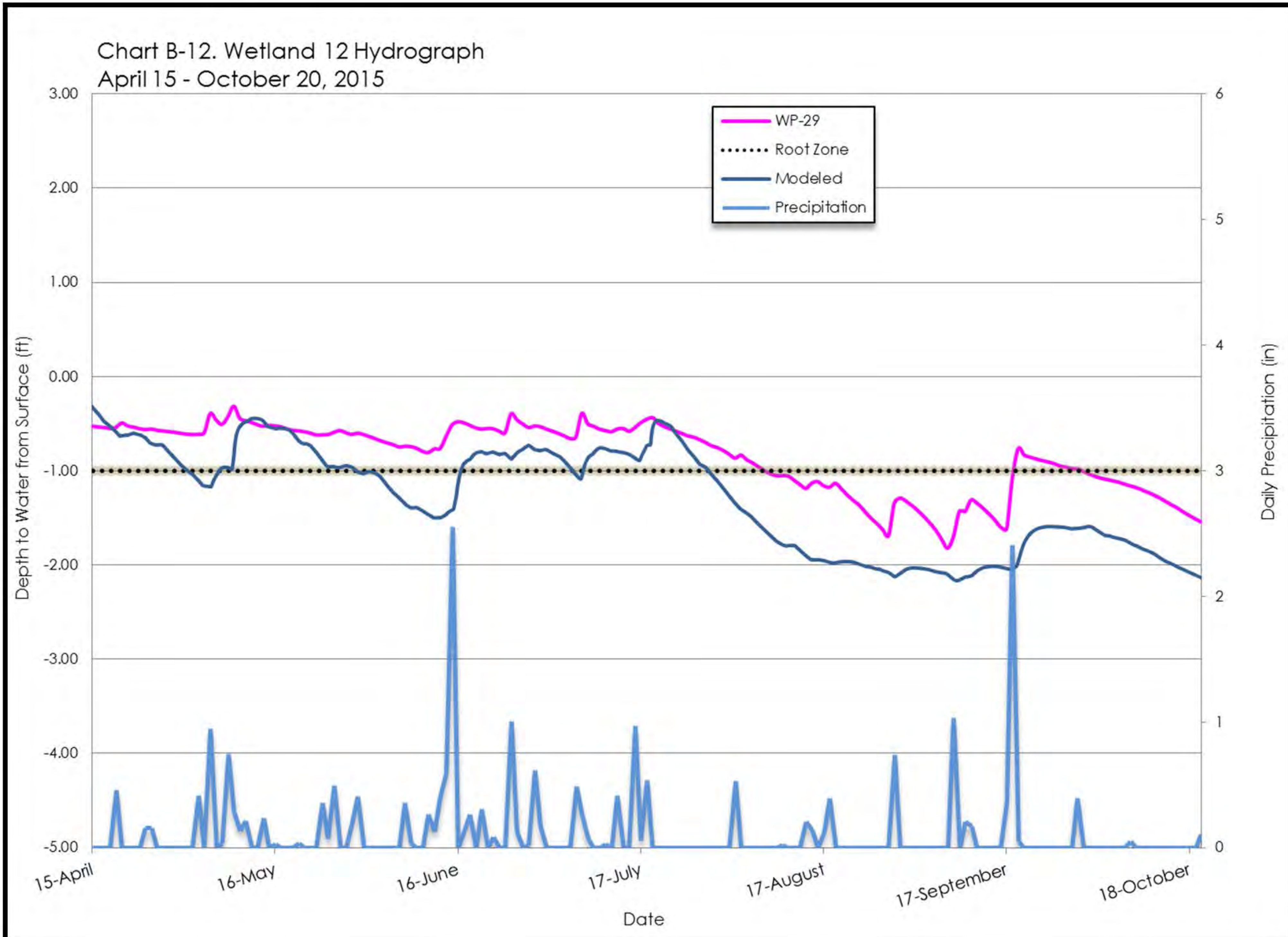


Chart B-12. Wetland 12 Hydrograph
April 15 - October 20, 2015
WP-29
Root Zone
Modeled
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6
5
4
3
2
1
0
15-April
16-May
16-June
17-July
17-August
17-September
18-October
Date

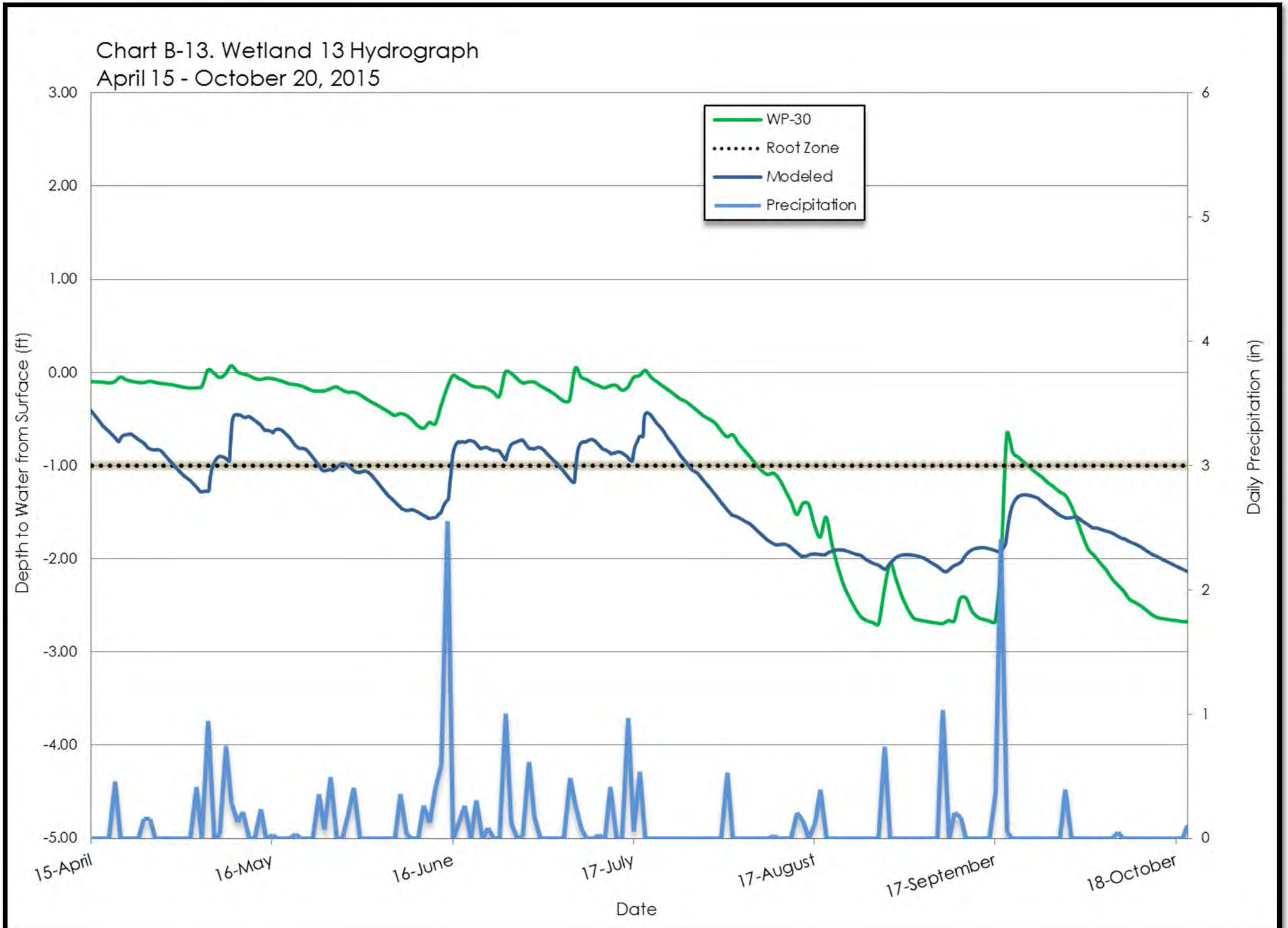


Chart B-13. Wetland 13 Hydrograph
April 15 - October 20, 2015
WP-30
Root Zone
Modeled
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6
5
4
3
2
1
0
15-April
16-May
16-June
17-July
17-August
17-September
18-October
Date

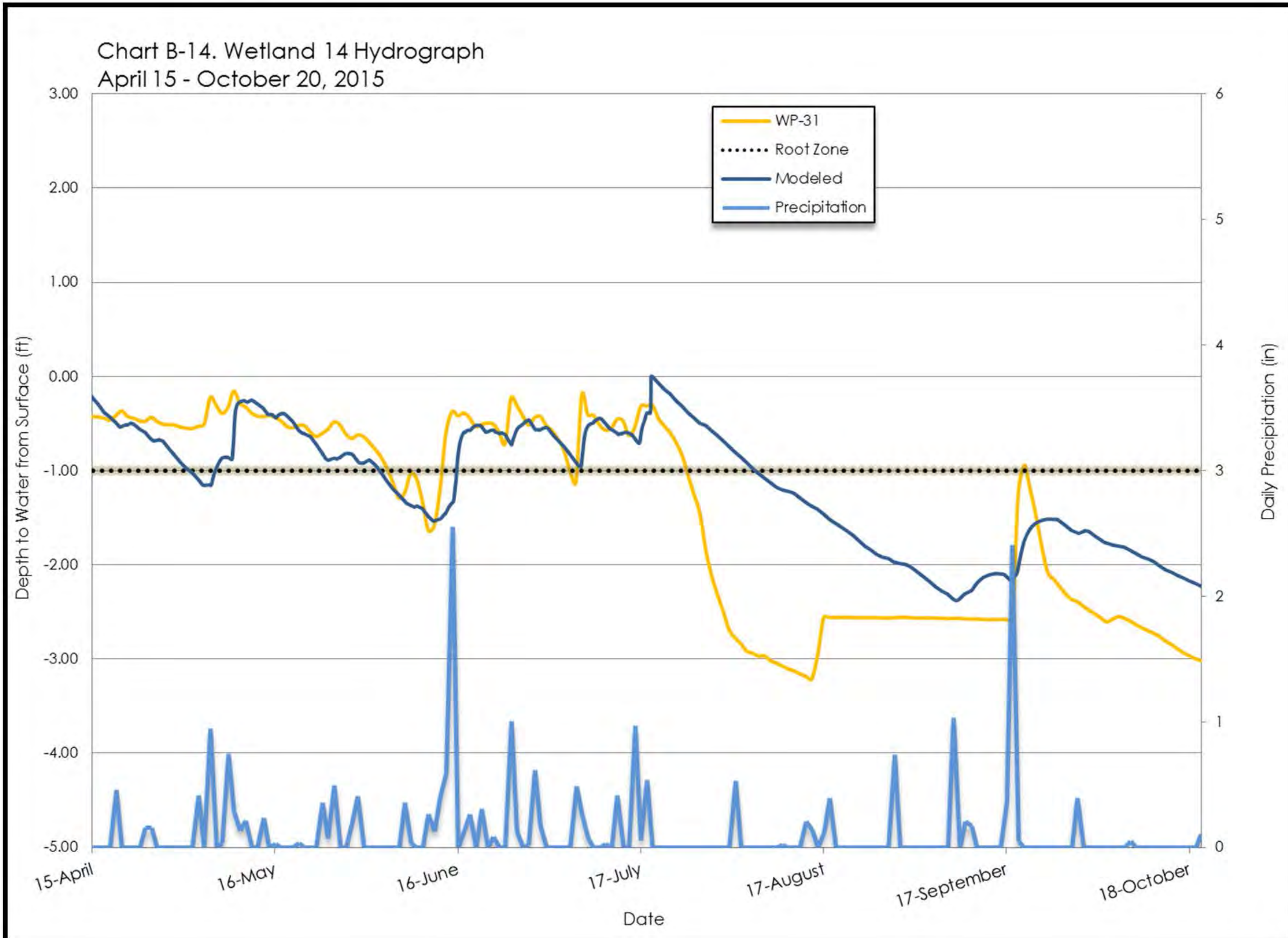


Chart B-14. Wetland 14 Hydrograph
April 15 - October 20, 2015
WP-31
Root Zone
Modeled
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6
5
4
3
2
1
0
15-April
16-May
16-June
17-July
17-August
17-September
18-October
Date

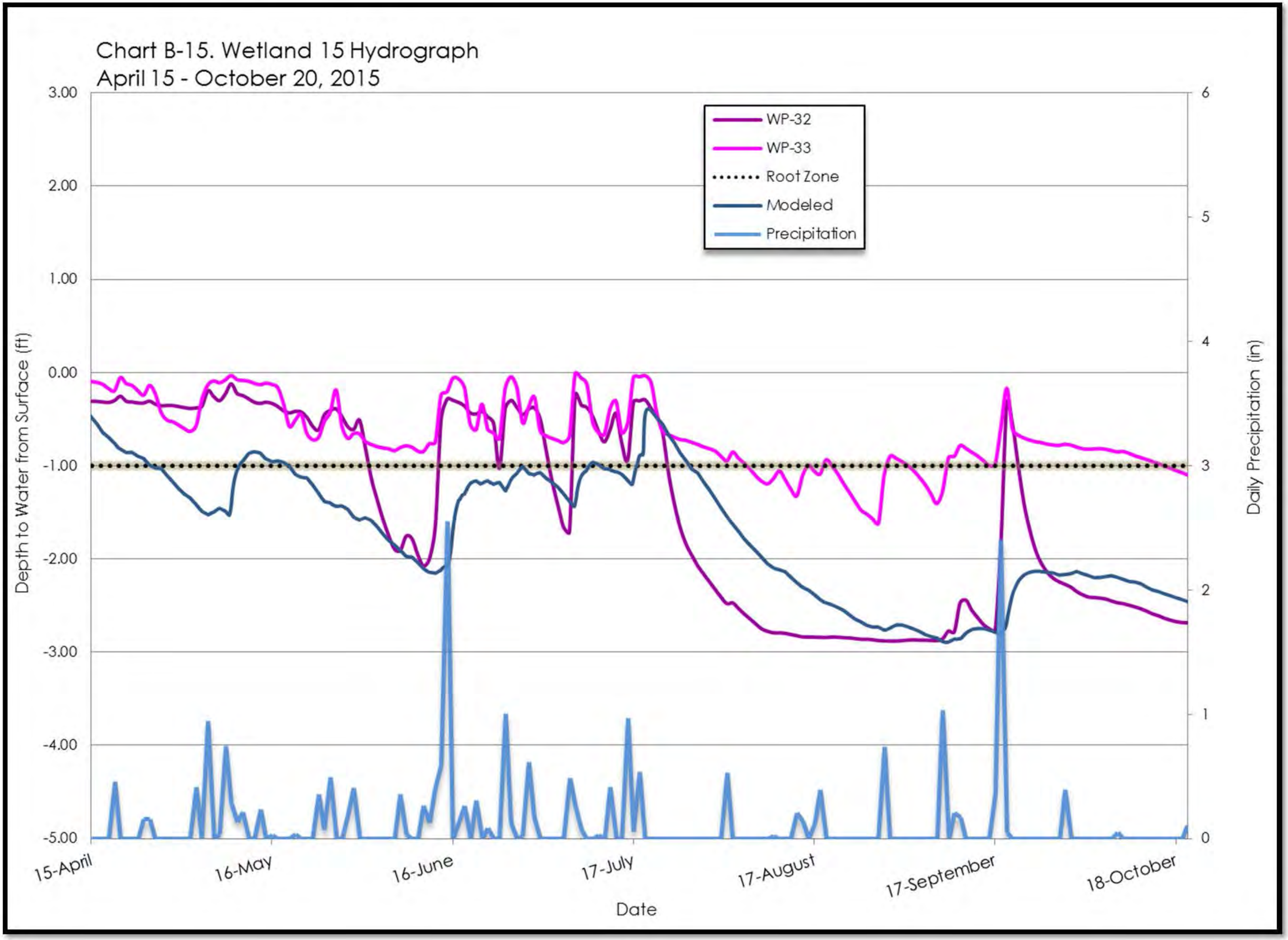


Chart B-15. Wetland 15 Hydrograph
April 15 - October 20, 2015
WP-32
WP-33
Root Zone
Modeled
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6
5
4
3
2
1
0
15-April
16-May
16-June
17-July
17-August
17-September
18-October
Date

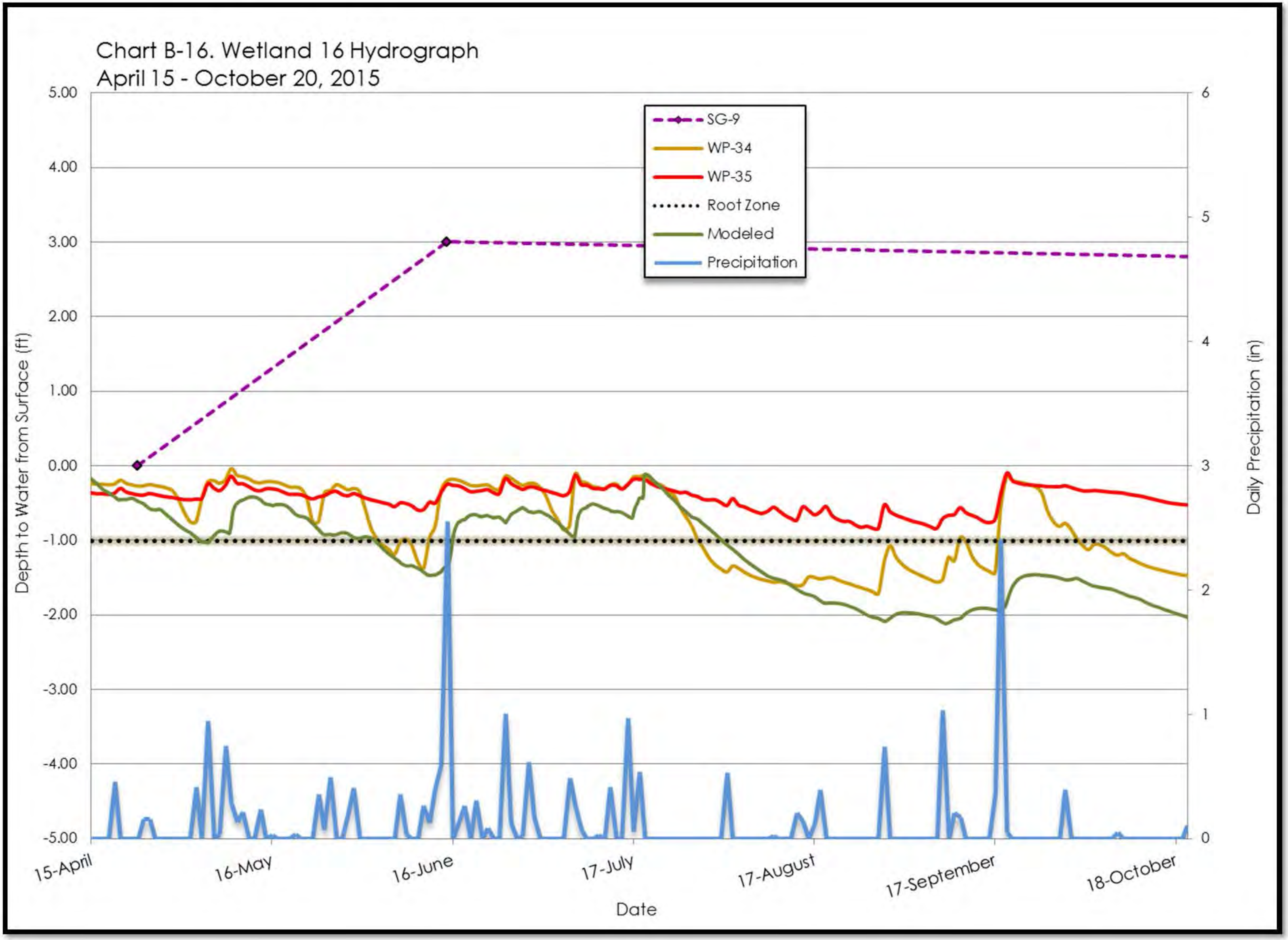


Chart B-16. Wetland 16 Hydrograph
April 15 - October 20, 2015
SG-9
WP-34
WP-35
Root Zone
Modeled
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6
5
4
3
2
1
0
15-April
16-May
16-June
17-July
17-August
17-September
18-October
Date

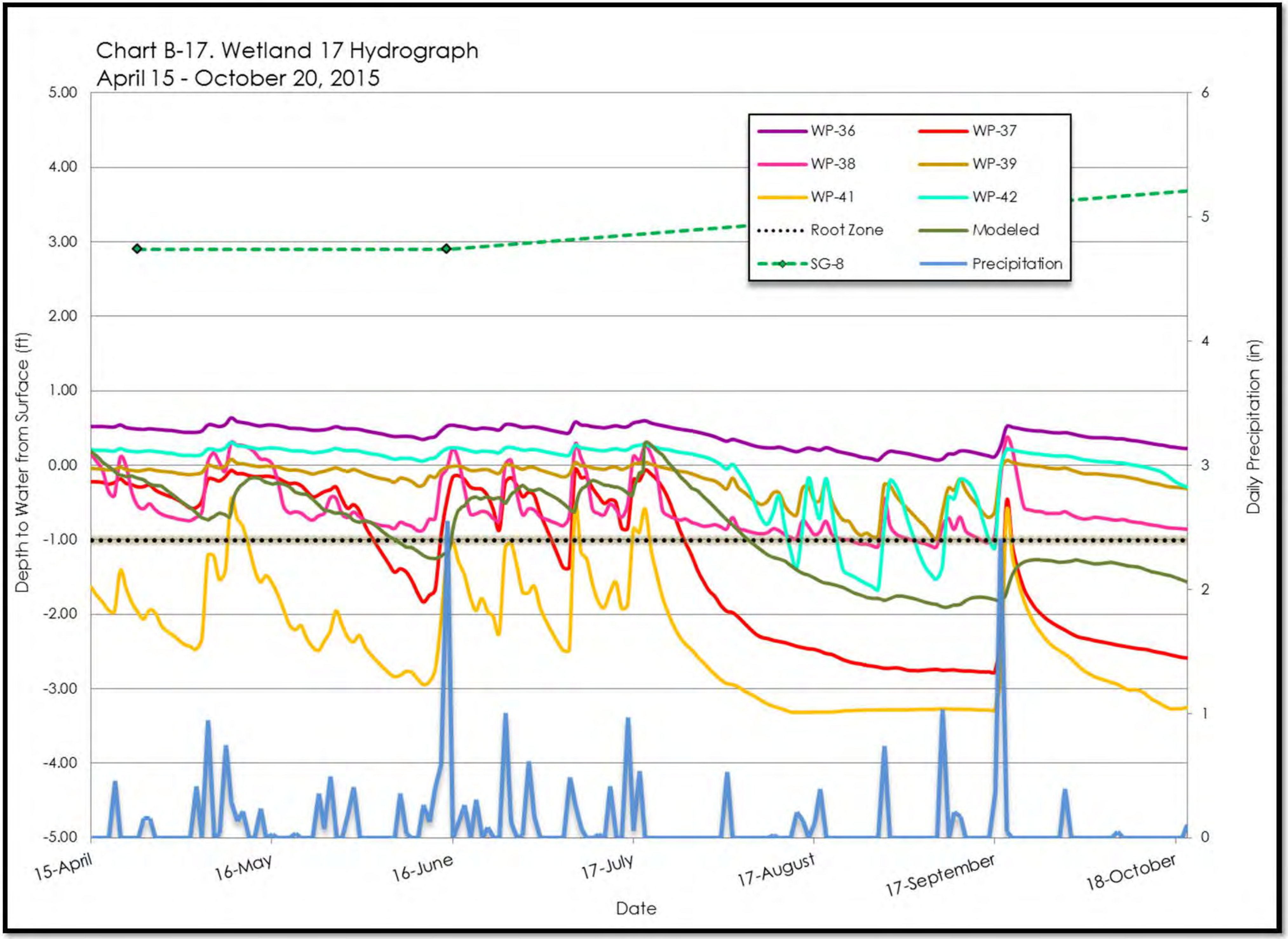


Chart B-17. Wetland 17 Hydrograph
April 15 - October 20, 2015
WP-36
WP-37
WP-38
WP-39
WP-41
WP-42
Root Zone
Modeled
SG-8
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6
5
4
3
2
1
0
15-April
16-May
16-June
17-July
17-August
17-September
18-October
Date

Appendix D – TINLEY CREEK WEST CALIBRATION GRAPHS

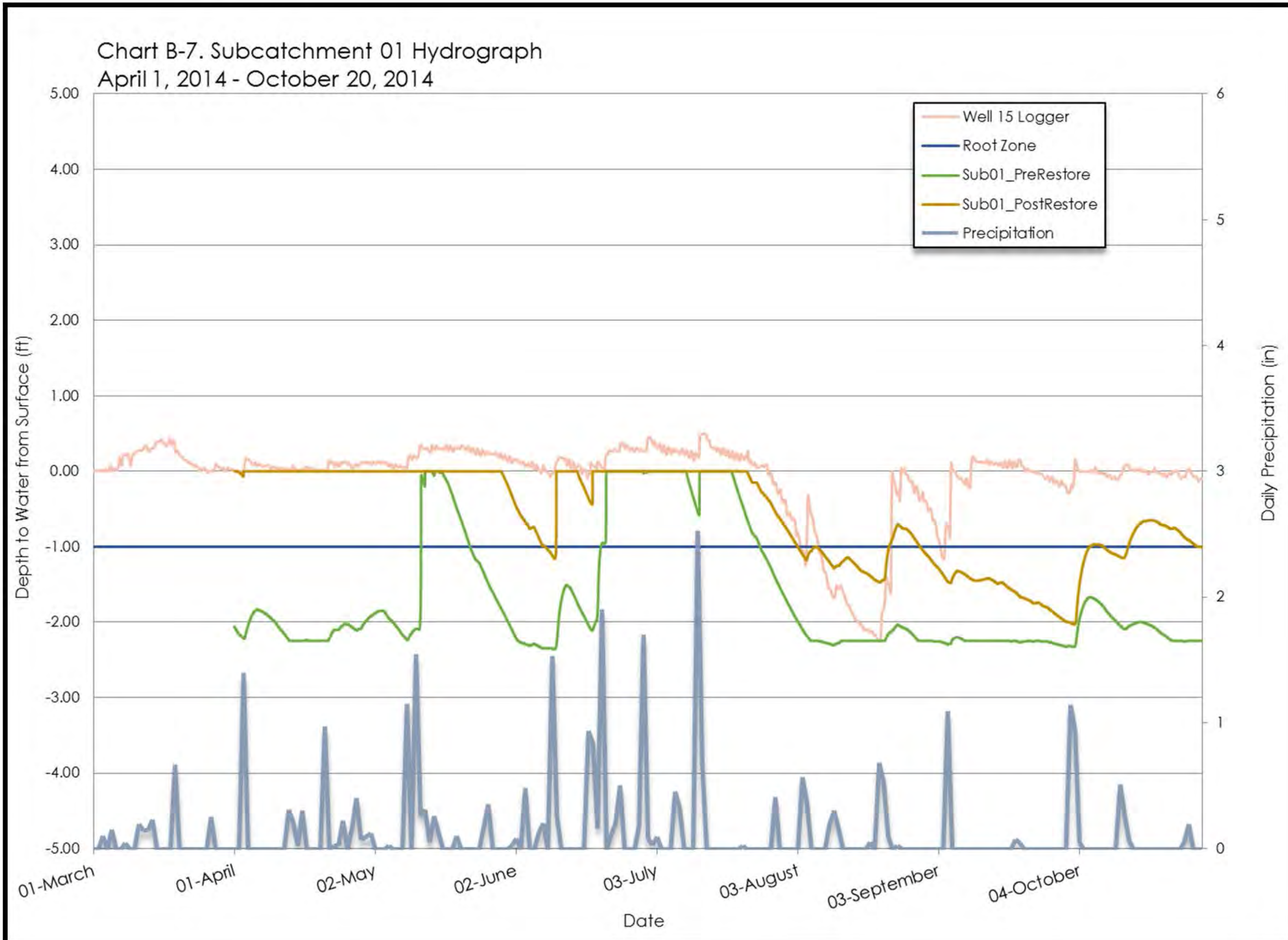


Chart B-7. Subcatchment 01 Hydrograph
April 1, 2014 - October 20, 2014
Well 15 Logger
Root Zone
Sub01_PreRestore
Sub01_PostRestore
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
Date
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6
5
4
3
2
1
0
01-March
01-April
02-May
02-June
03-July
03-August
03-September
04-October

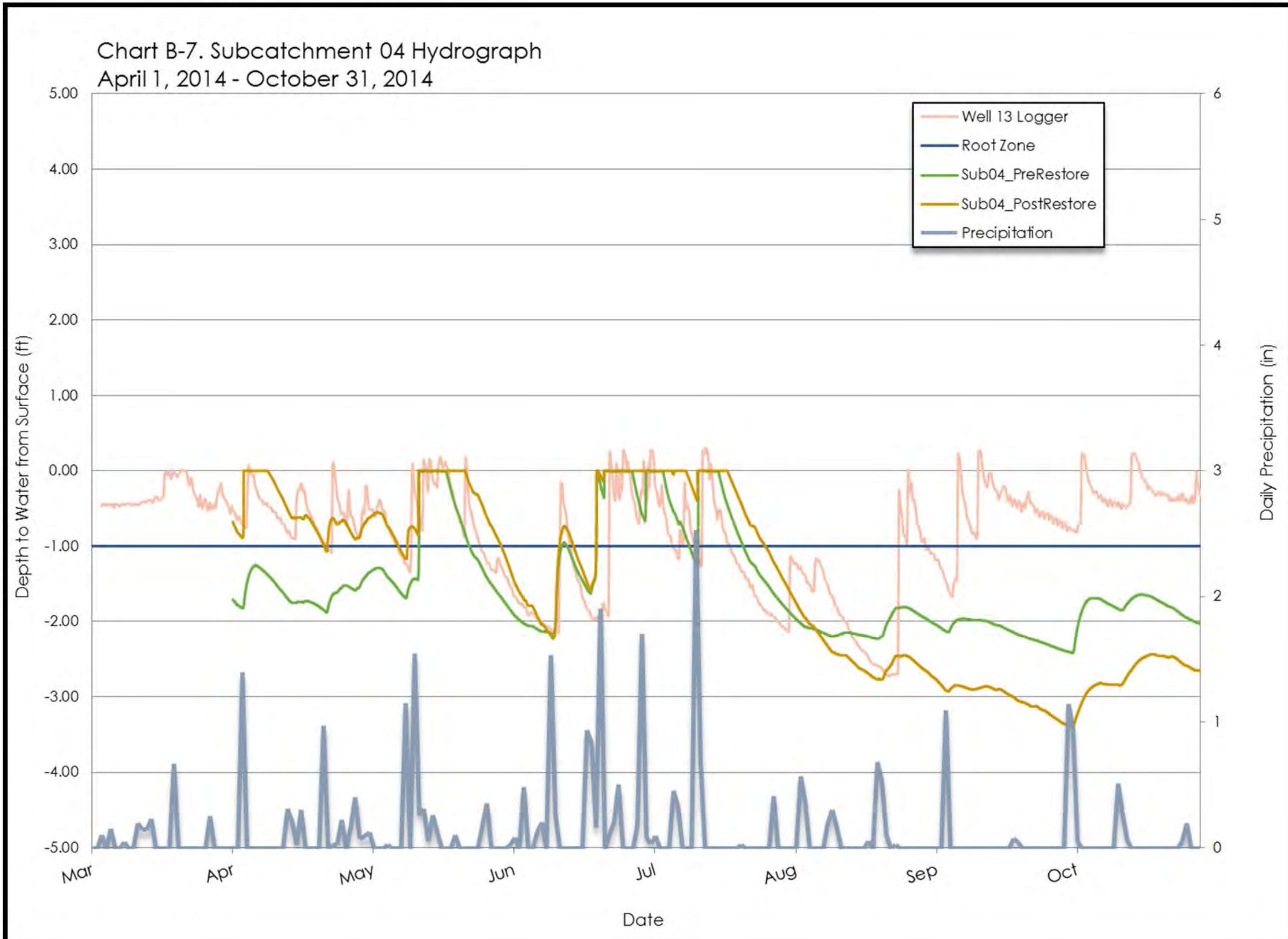


Chart B-7. Subcatchment 04 Hydrograph
April 1, 2014 - October 31, 2014
Well 13 Logger
Root Zone
Sub04_PreRestore
Sub04_PostRestore
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
Date
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6
5
4
3
2
1
0
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct

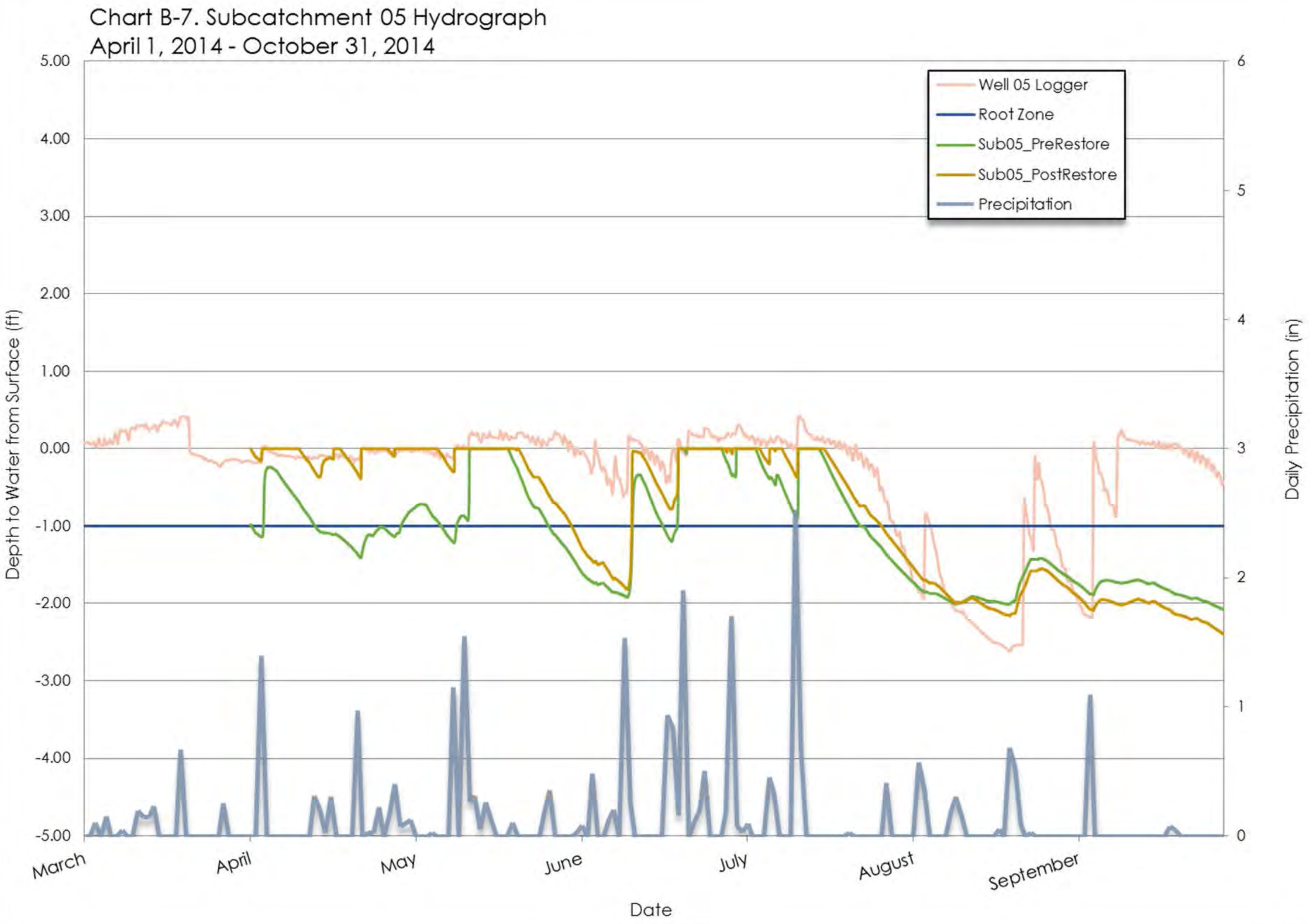


Chart B-7. Subcatchment 05 Hydrograph
April 1, 2014 - October 31, 2014
Well 05 Logger
Root Zone
Sub05_PreRestore
Sub05_PostRestore
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6
5
4
3
2
1
0
March
April
May
June
July
August
September
Date

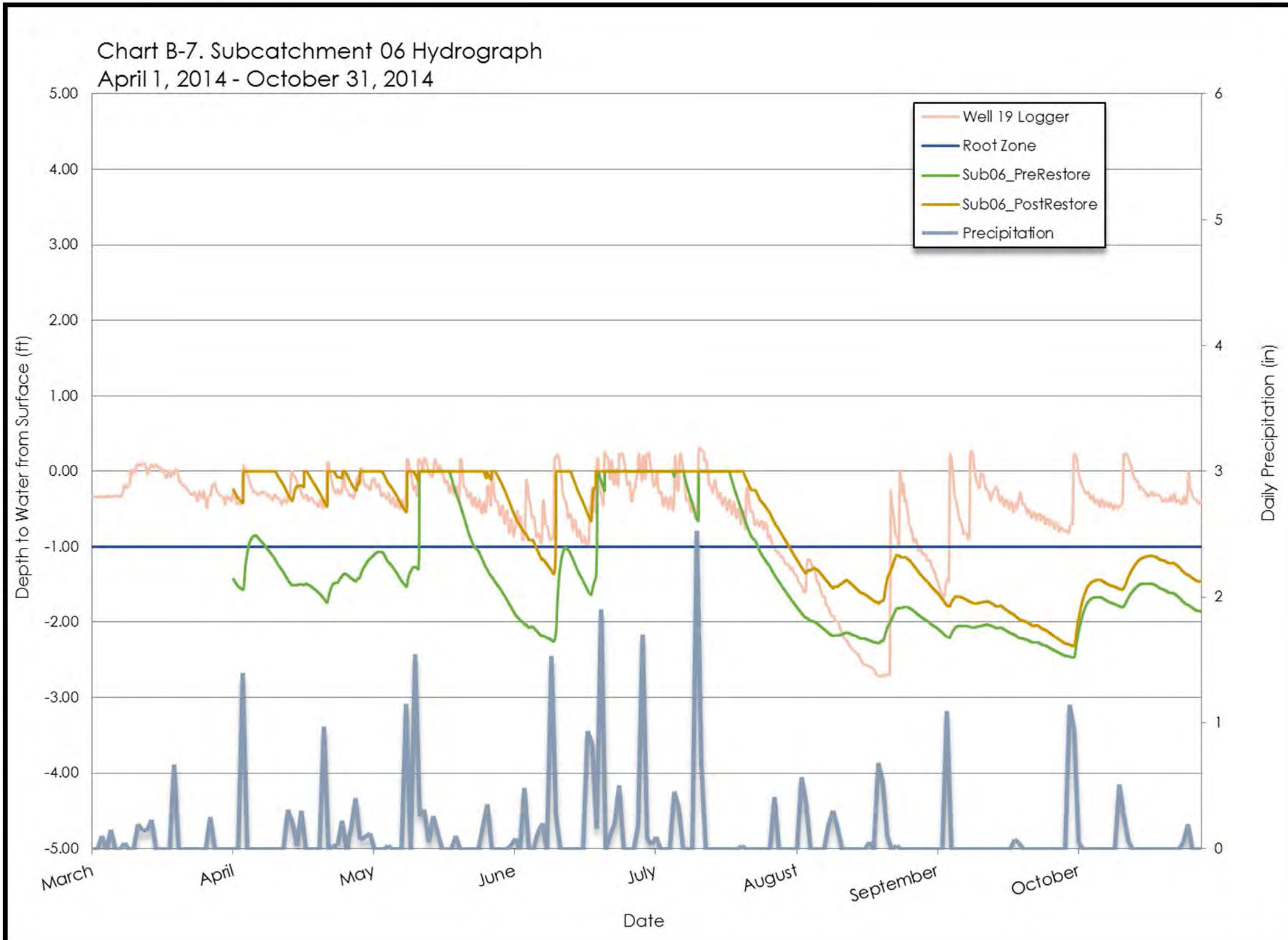


Chart B-7. Subcatchment 06 Hydrograph
April 1, 2014 - October 31, 2014
Well 19 Logger
Root Zone
Sub06_PreRestore
Sub06_PostRestore
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6
5
4
3
2
1
0
March
April
May
June
July
August
September
October
Date

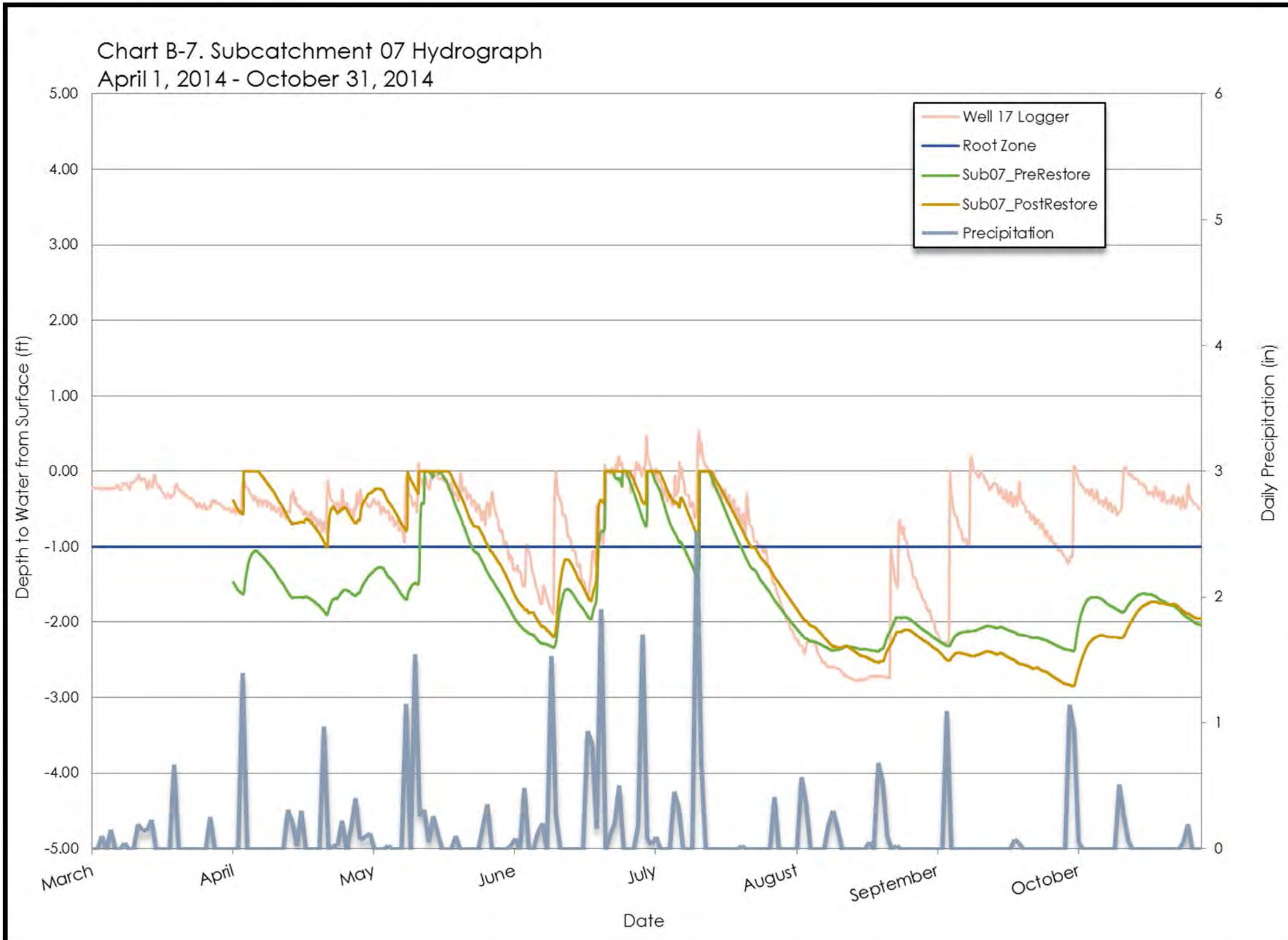
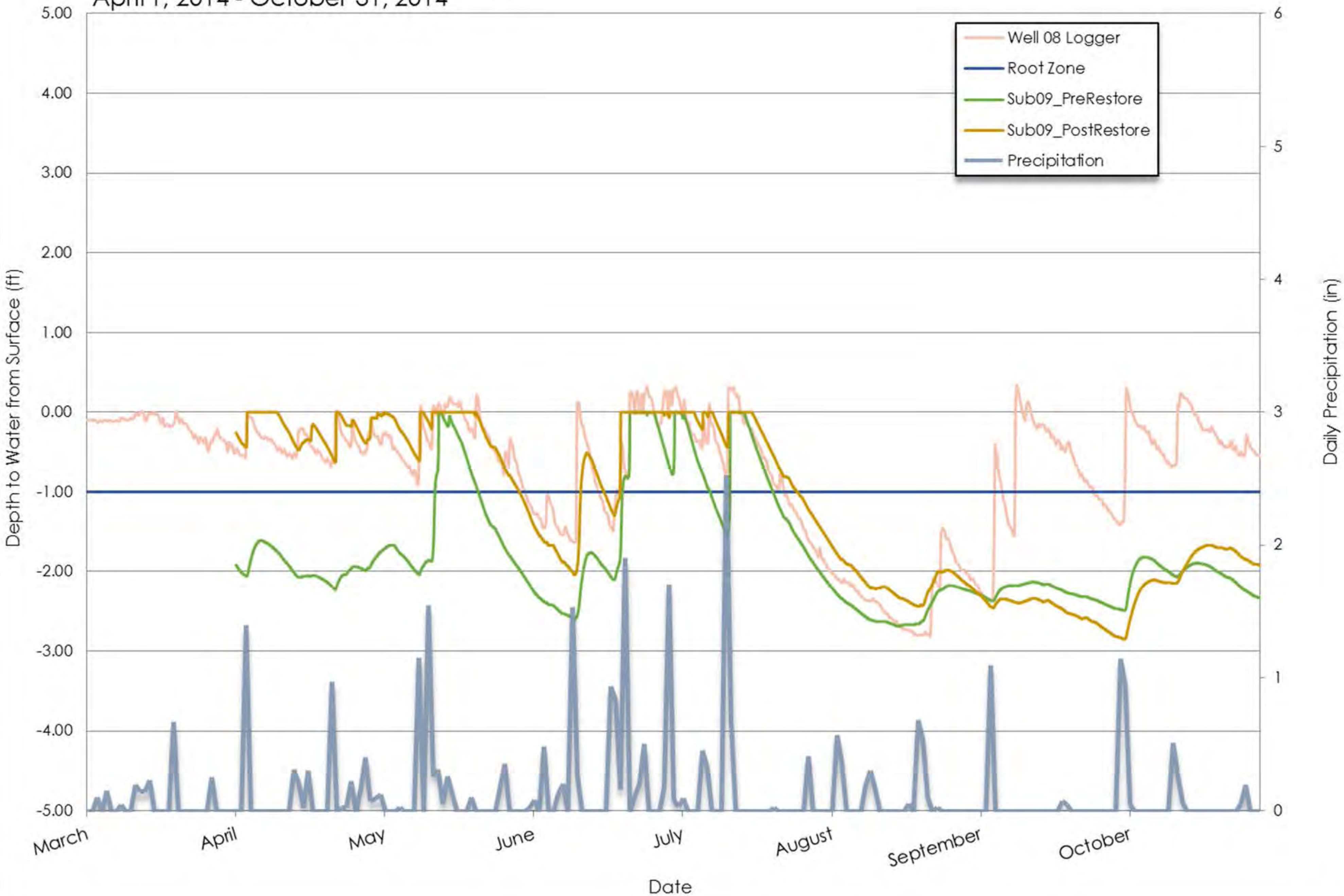


Chart B-7. Subcatchment 07 Hydrograph
April 1, 2014 - October 31, 2014
Well 17 Logger
Root Zone
Sub07_PreRestore
Sub07_PostRestore
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6
5
4
3
2
1
0
March
April
May
June
July
August
September
October
Date

Chart B-7. Subcatchment 09 Hydrograph
April 1, 2014 - October 31, 2014



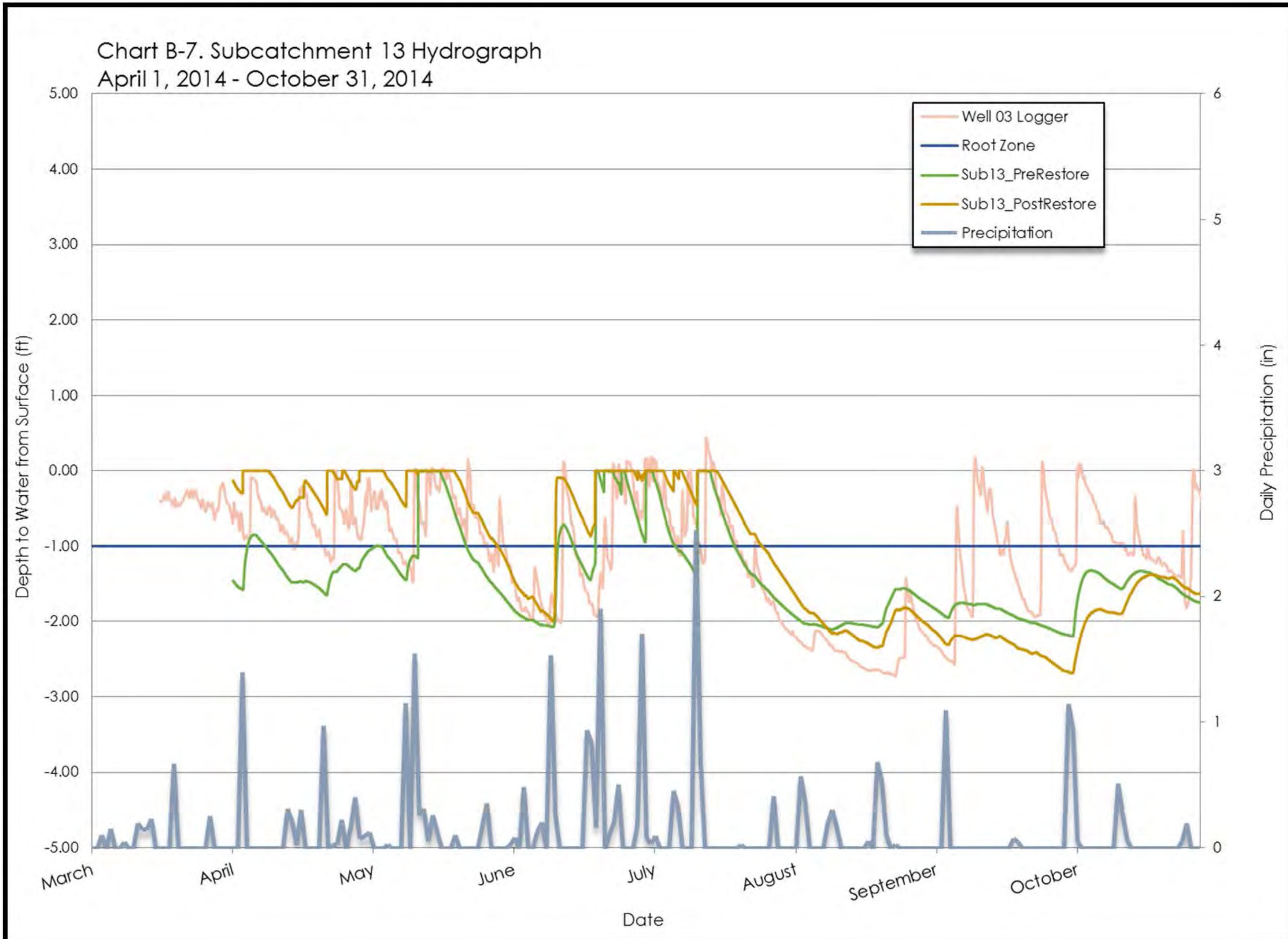


Chart B-7. Subcatchment 13 Hydrograph
April 1, 2014 - October 31, 2014
Well 03 Logger
Root Zone
Sub13_PreRestore
Sub13_PostRestore
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6
5
4
3
2
1
0
March
April
May
June
July
August
September
October
Date

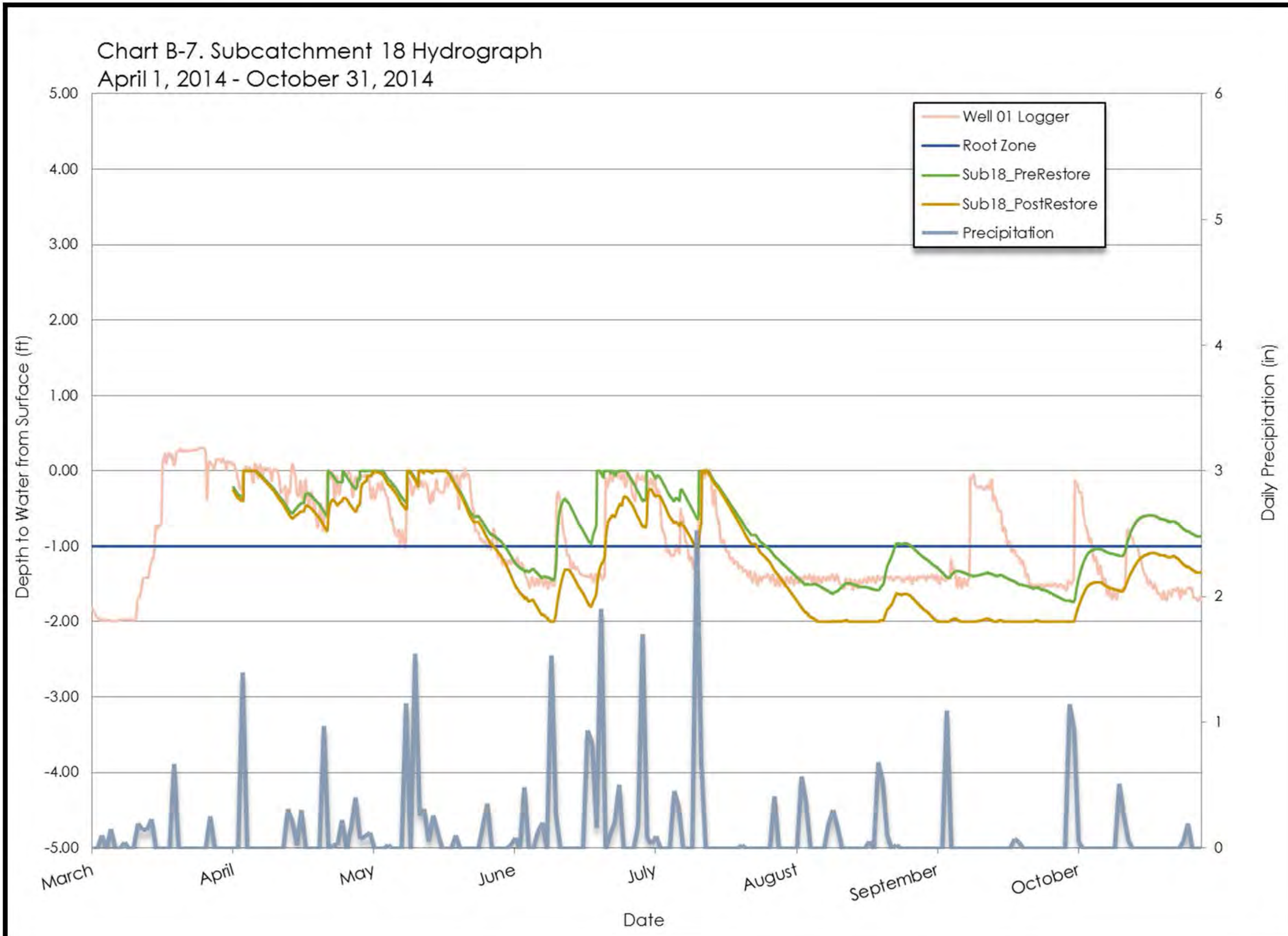


Chart B-7. Subcatchment 18 Hydrograph
April 1, 2014 - October 31, 2014
Well 01 Logger
Root Zone
Sub18_PreRestore
Sub18_PostRestore
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6
5
4
3
2
1
0
March
April
May
June
July
August
September
October
Date

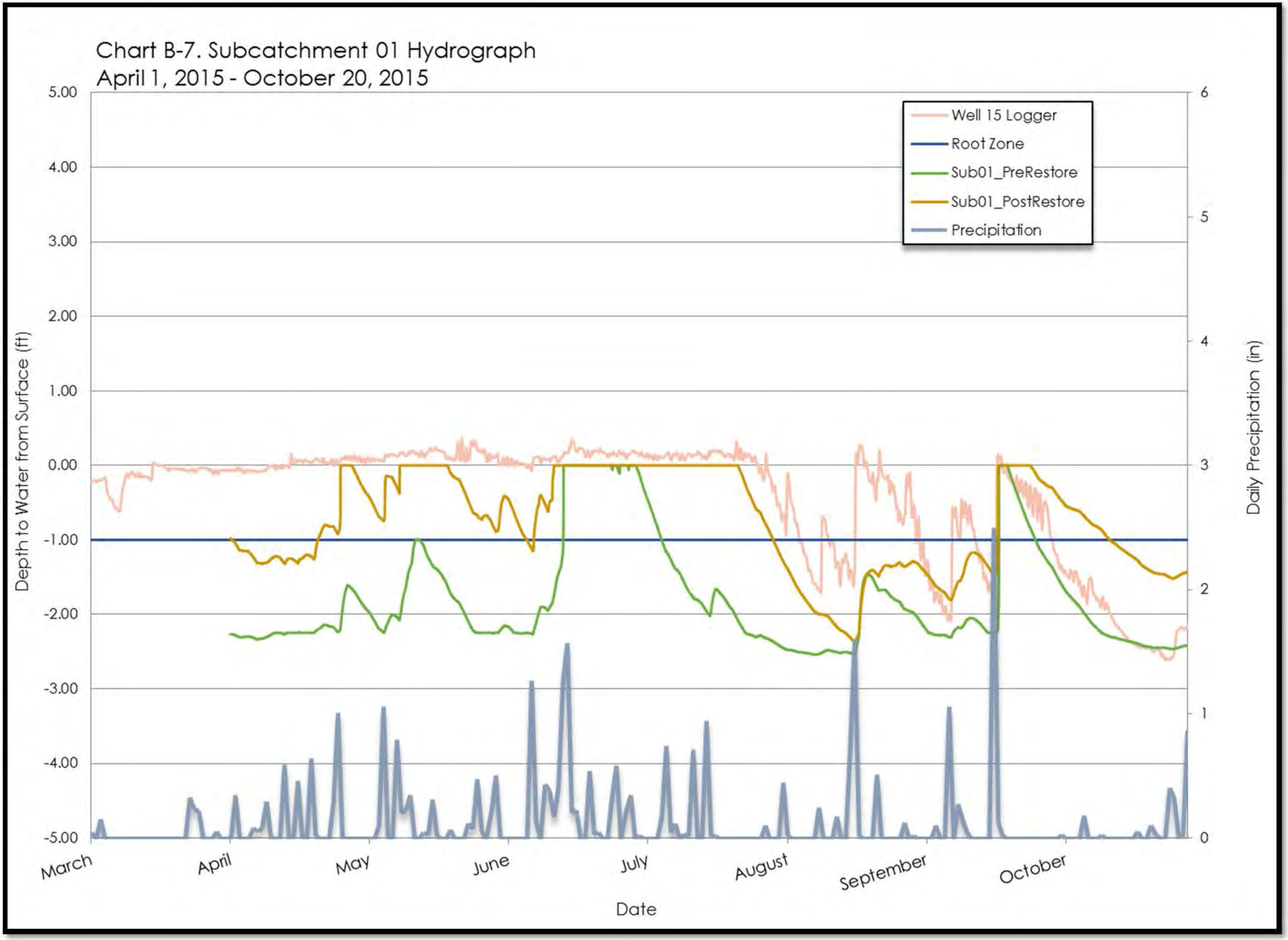


Chart B-7. Subcatchment 01 Hydrograph
April 1, 2015 - October 20, 2015
Well 15 Logger
Root Zone
Sub01_PreRestore
Sub01_PostRestore
Precipitation
Depth to Water from Surface (ft)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
Daily Precipitation (in)
6
5
4
3
2
1
0
March
April
May
June
July
August
September
October
Date

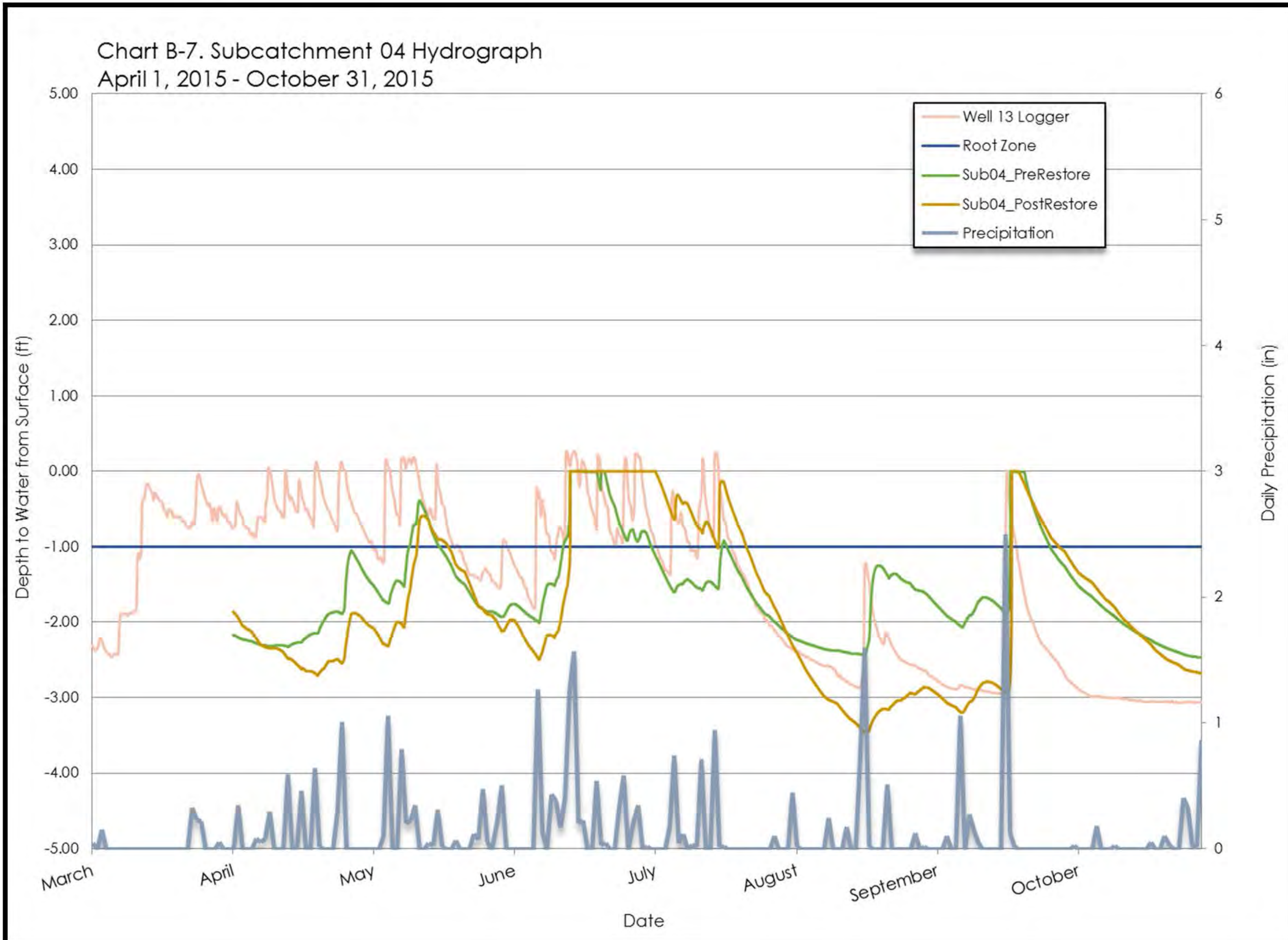


Chart B-7. Subcatchment 04 Hydrograph
April 1, 2015 - October 31, 2015
Well 13 Logger
Root Zone
Sub04_PreRestore
Sub04_PostRestore
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6
5
4
3
2
1
0
March
April
May
June
July
August
September
October
Date

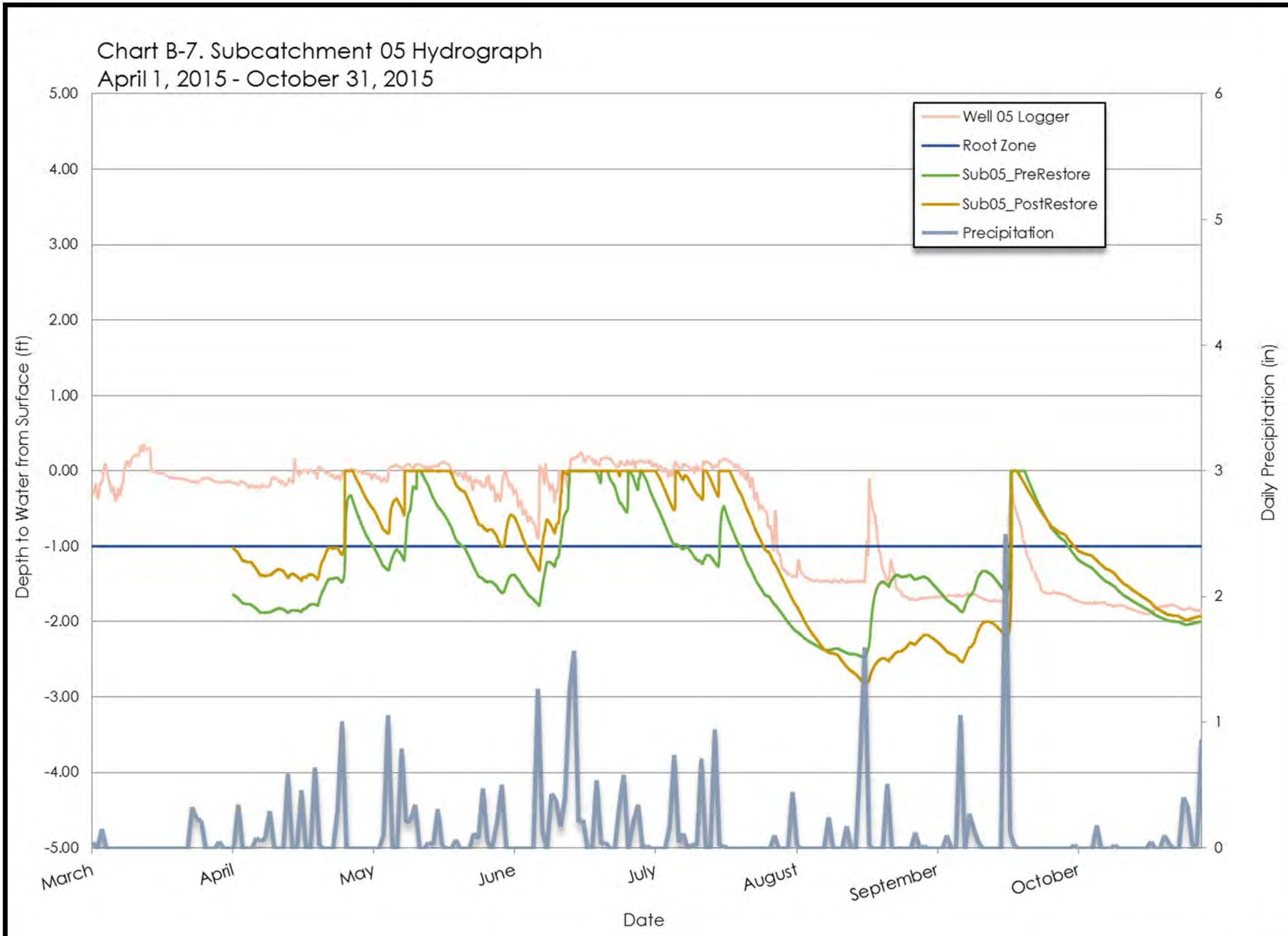


Chart B-7. Subcatchment 05 Hydrograph
April 1, 2015 - October 31, 2015
Well 05 Logger
Root Zone
Sub05_PreRestore
Sub05_PostRestore
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6
5
4
3
2
1
0
March
April
May
June
July
August
September
October
Date

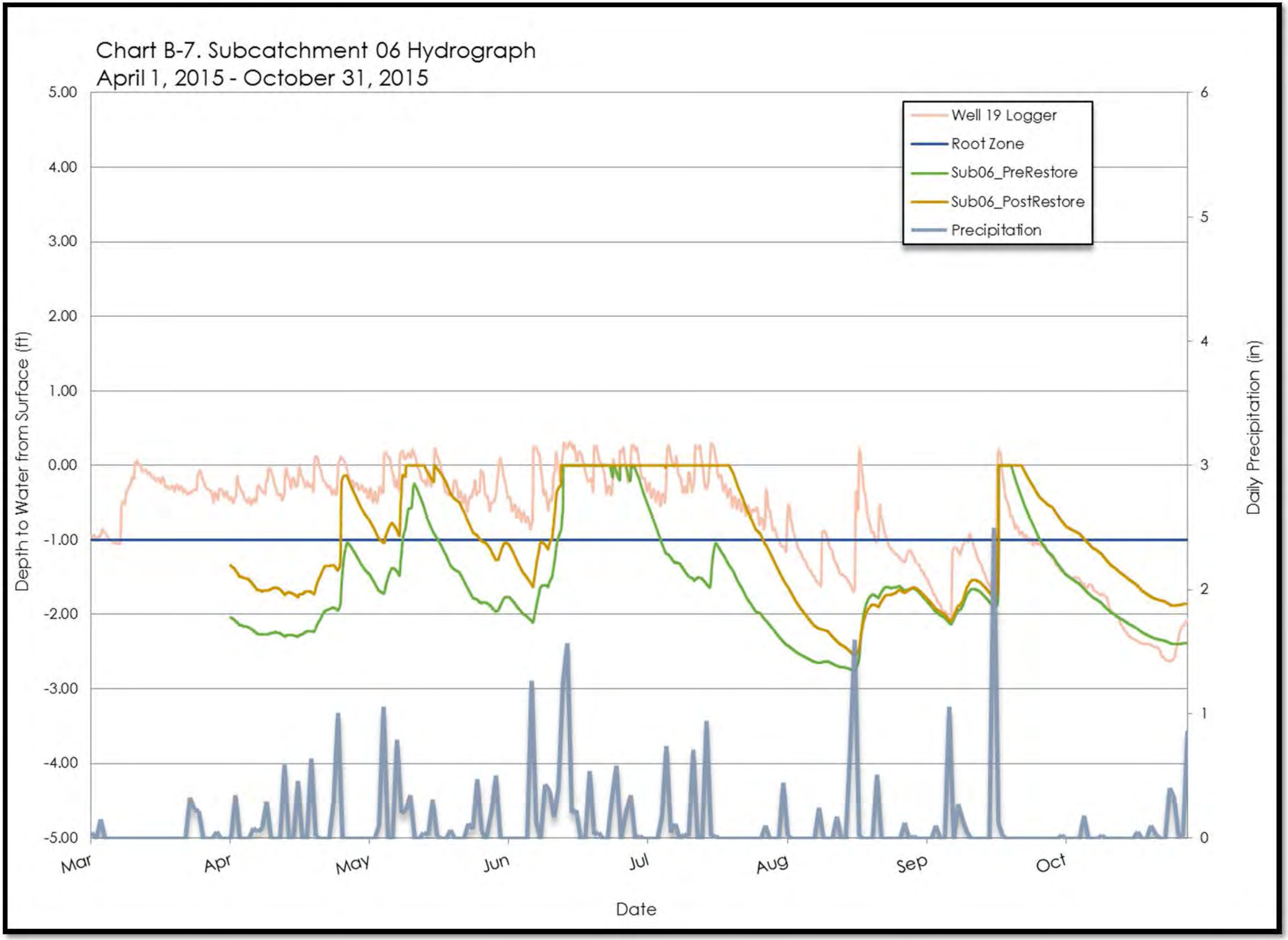


Chart B-7. Subcatchment 06 Hydrograph
April 1, 2015 - October 31, 2015
Well 19 Logger
Root Zone
Sub06_PreRestore
Sub06_PostRestore
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6
5
4
3
2
1
0
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Date

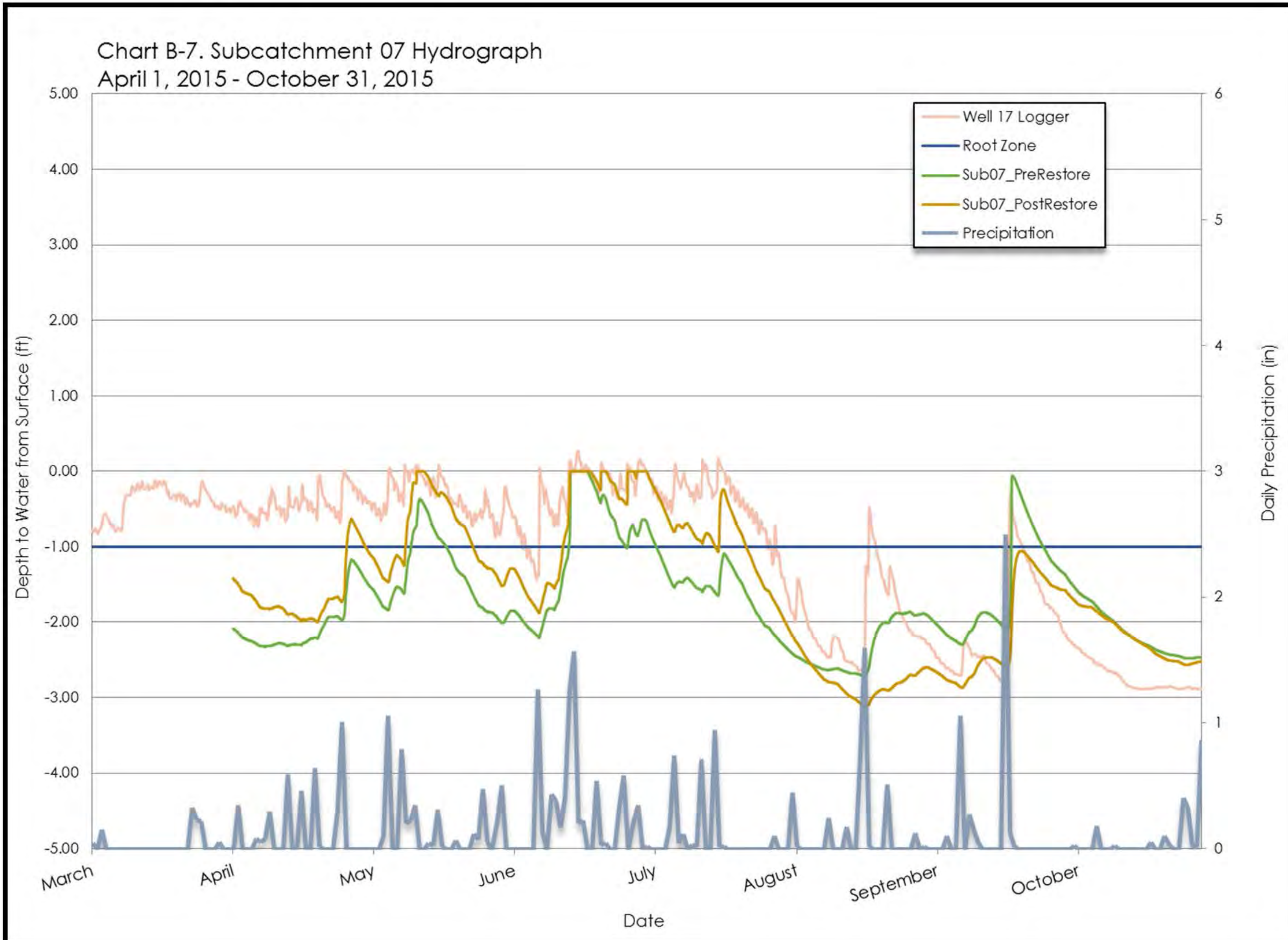


Chart B-7. Subcatchment 07 Hydrograph
April 1, 2015 - October 31, 2015
Well 17 Logger
Root Zone
Sub07_PreRestore
Sub07_PostRestore
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6
5
4
3
2
1
0
March
April
May
June
July
August
September
October
Date

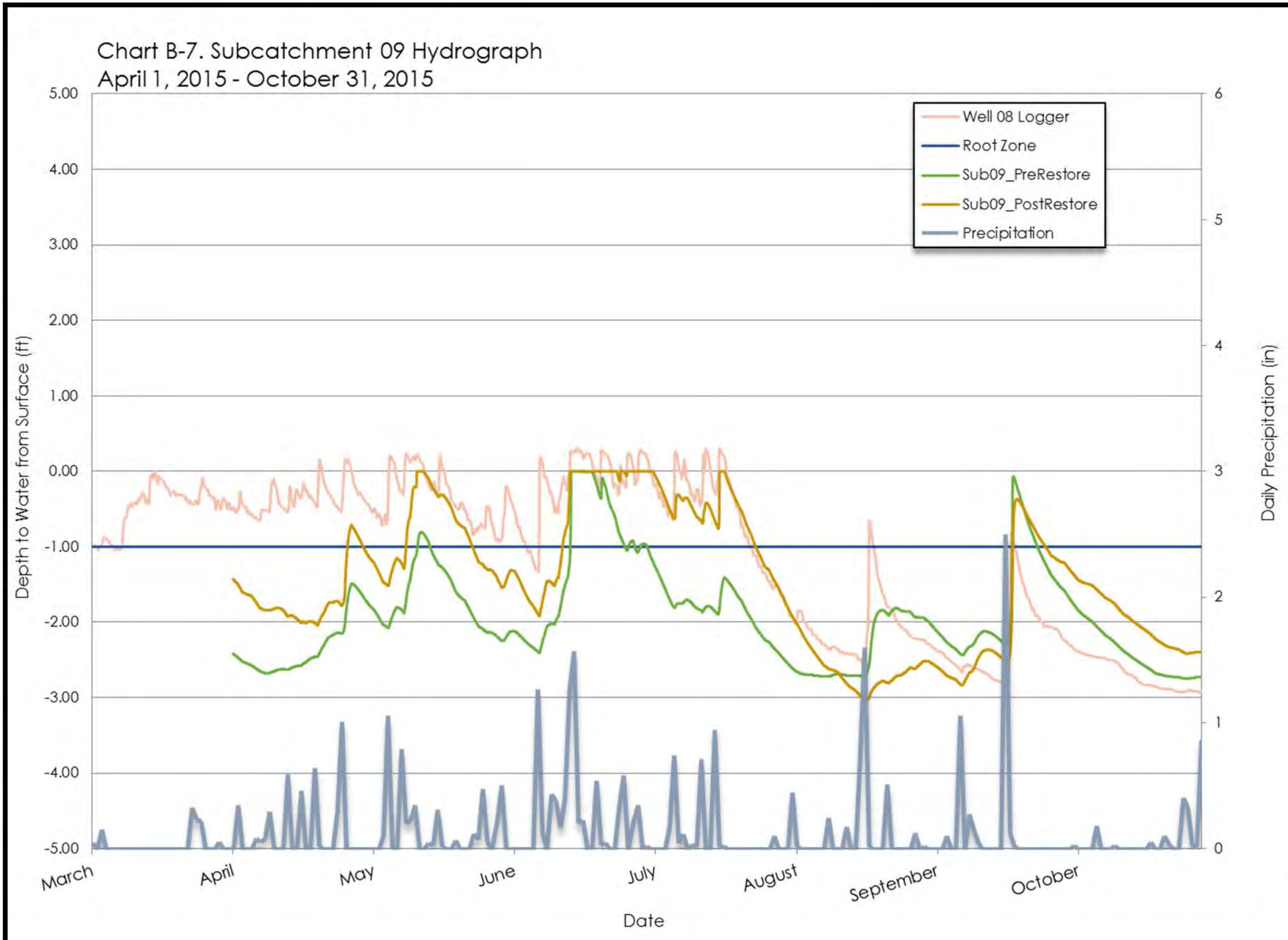


Chart B-7. Subcatchment 09 Hydrograph
April 1, 2015 - October 31, 2015
Well 08 Logger
Root Zone
Sub09_PreRestore
Sub09_PostRestore
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6
5
4
3
2
1
0
March
April
May
June
July
August
September
October
Date

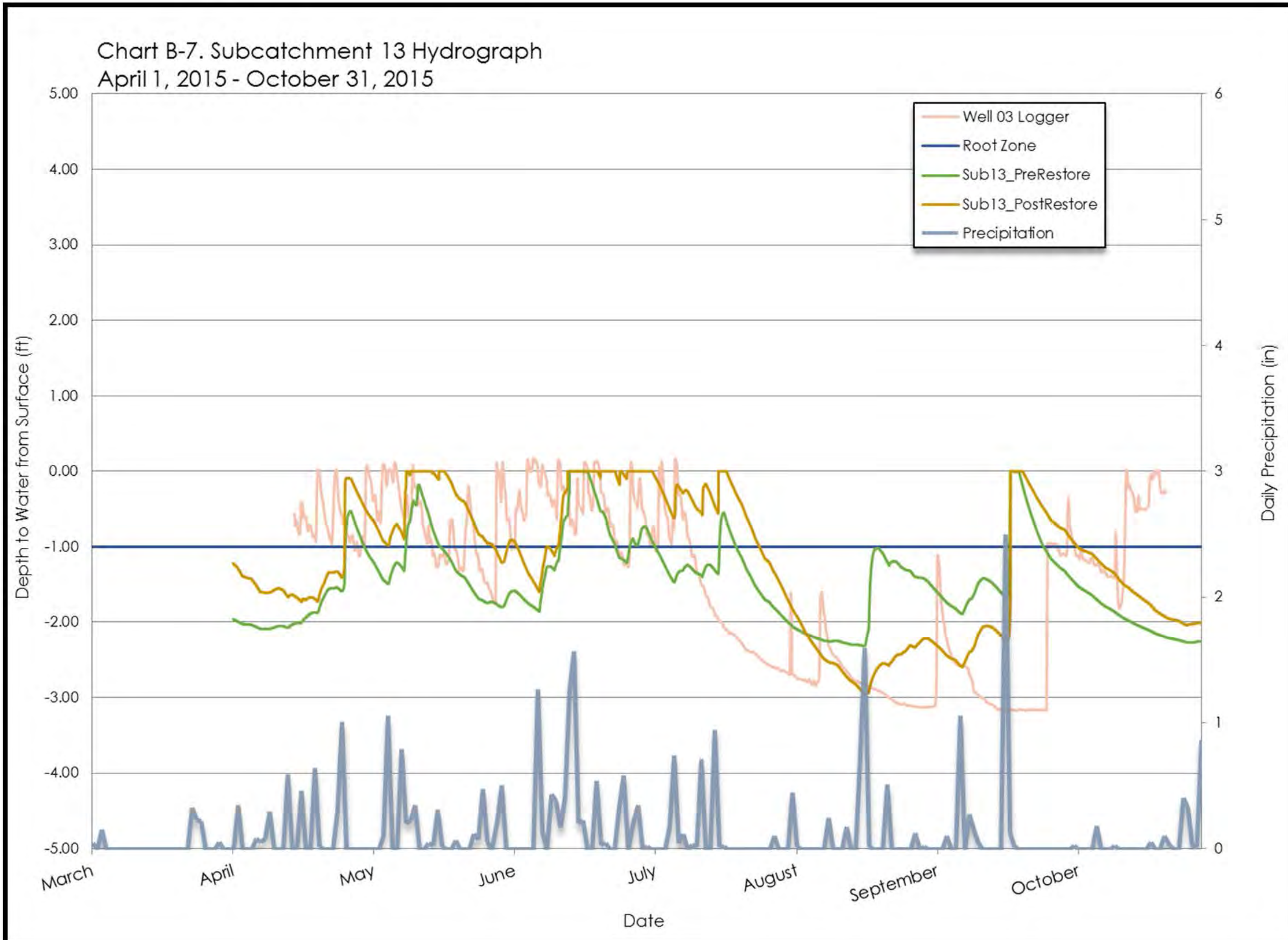


Chart B-7. Subcatchment 13 Hydrograph
April 1, 2015 - October 31, 2015
Well 03 Logger
Root Zone
Sub13_PreRestore
Sub13_PostRestore
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6
5
4
3
2
1
0
March
April
May
June
July
August
September
October
Date

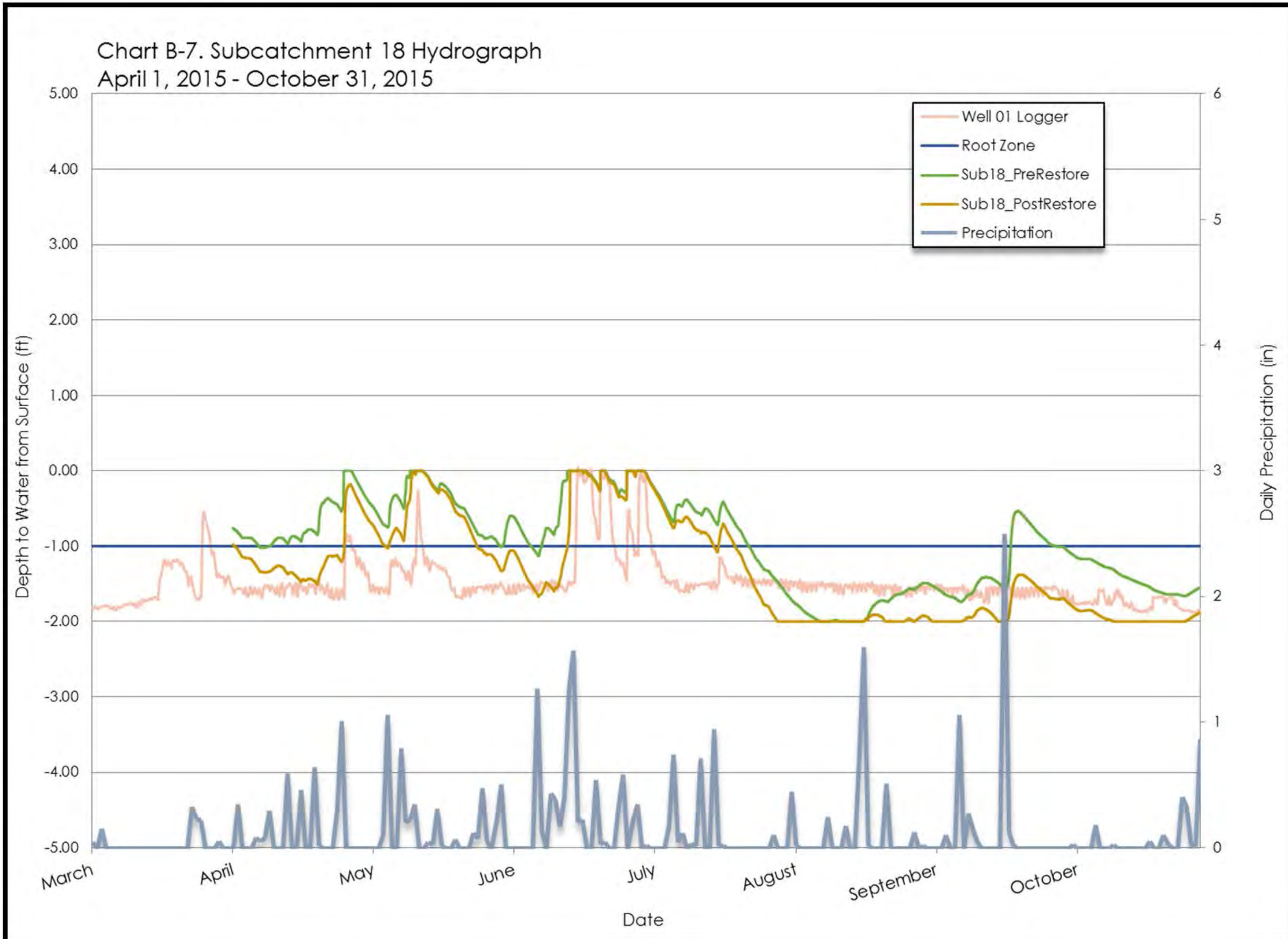


Chart B-7. Subcatchment 18 Hydrograph
April 1, 2015 - October 31, 2015
Well 01 Logger
Root Zone
Sub18_PreRestore
Sub18_PostRestore
Precipitation
Depth to Water from Surface (ft)
Daily Precipitation (in)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
6
5
4
3
2
1
0
March
April
May
June
July
August
September
October
Date