# MEMORANDUM

**TO:** Lynn Small, Deputy Director Environmental Compliance

**FROM:** Mike Deas, P.E., Ph.D.
Dave Smith, Ph.D.

**DATE:** 29 April 2009

**SUBJECT:** Receiving Water Quality Limit Compliance Assurance and Monitoring Plan

## *INTRODUCTION*

Provision VI.B.2 of North Coast Regional Water Quality Control Board (RWQCB) Order No. R1-2006-0045 states the following:

> The Discharger may submit a proposal to monitor receiving water at locations different than receiving water locations specified in section VIII of the MRP. The proposal must be received by the Executive Officer within 180 days of the effective date of this Order and specify monitoring locations that are acceptable to the Executive Officer for the purpose of demonstrating compliance with this Order. The Executive Officer will inform the Discharger within 90 days after receipt of the proposal whether the alternative monitoring locations are acceptable. In the interim, the Discharger shall comply with interim receiving water monitoring requirements using interim receiving water monitoring locations, as specified in Attachment E-5 of the MRP. If an acceptable alternative proposal is not timely received and approved by the Executive Officer, the downstream receiving water monitoring locations specified in the MRP (section VIII) shall replace interim receiving water monitoring locations in Attachment E-5 effective immediately.

The City of Santa Rosa submitted the *Receiving Water Quality Limit Compliance Assurance and Monitoring Approach* dated May 5, 2007 (Proposed Approach) to RWQCB for consideration. RWQCB responded with an August 7, 2007, letter conceptually approving the Proposed Approach. The Proposed Approach identified additional work needed to fully implement the Proposed Approach on page 21. This report addresses the additional work items prepared for submittal by the City of Santa Rosa to RWQCB consistent with Provision VI.B.2 and the August 7 conceptual approval letter.

This report presents a framework to determine the appropriate daily discharge volume and verify compliance with receiving water quality limits. The framework recognizes that the momentum of recycled water exiting the outfall results in initial mixing or dilution[1] within very close proximity to the outfall: zone of initial dilution. With knowledge of initial dilution and the quality of recycled water being discharged and the quality of the receiving water, the resulting concentration of each constituent for which a receiving water limit exists can be calculated. Because the amount of initial dilution is dependent on recycled water flow, the amount of recycled water being discharged can be modulated to achieve compliance. Estimates of water quality and flow based on the preceding day's condition can be used to estimate the quantity of recycled water that can be discharged in compliance with receiving water limits, and then actual water quality and flow data used to verify compliance. For this framework, temperature, dissolved oxygen, turbidity, and pH are assessed for receiving water compliance. Constituents can be readily added or removed from the framework.

This report is an extension of a previous memorandum (MSC, 2007) on feasibility assessment of the approach. In MSC (2007) a multidimensional hydrodynamic model was applied to explore the relationship between flow, stage, and local velocities in the Laguna and Santa Rosa Creek for a range of discharge conditions to develop an approach to guide day-to-day discharge management. This memorandum expands on MSC (2007). Specifically, this memorandum includes the following sections:

- **Study Area**. Updated topography in the receiving water environment is described.

- **Model Refinement**. The application of a companion two-dimensional water quality model RMA-11, wherein dilution at the edge of the zone of initial dilution can be directly quantified, is described.

- **Discharge Operations and Compliance Verification**. A method to estimating the quantity of water that can be discharged in compliance with receiving water limits and a method for verifying compliance are provided.

## *STUDY AREA*

Delta Pond is located in the Laguna de Santa Rosa immediately upstream of the confluence with Santa Rosa Creek. Discharge from Delta Pond occurs through a 48 inch

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1 Initial dilution is the process that results in rapid and irreversible turbulent mixing of a discharge with receiving water. SWRCB (2005) states that "[F]or shallow submerged discharges, surface discharges, and non-buoyant discharges…turbulent mixing results primarily from the momentum of discharge. Initial dilution in these cases is considered to be complete when the momentum induced velocity of the discharge ceases to produce significant mixing of the waste, or the plume reaches a fixed distance from the discharge to be specified by the Regional Board, whichever results in the lower mixing estimate for initial dilution" (Page 26, SWRCB. 2005. California Ocean Plan)

diameter pipe from the northwest corner of the reservoir. At low water (e.g., summer flows), the discharge point lies within the channel currently occupied by Santa Rosa Creek. However, higher winter flows inundate the low topography of the region and the discharge generally flows into a flooded Laguna system. The study area focuses on a the Laguna and Santa Rosa Creek from approximately 1,600 feet upstream of the confluence to approximately 500 feet below the confluence where the Laguna passes under the Guerneville Road bridge. The study area and topography are shown in Figure 1.


**Figure 1. Study area and topography**

Primary data requirements for RMA-2 and RMA-11 include a topographic representation of the study area, location of inflows and outflows, inflow rate, and a representation of the outflow condition (e.g., a weir, stage discharge, or other relationship).

Initial topographic representation was augmented with field surveys in September of 2007. A relative coordinate system was established prior to surveying, and included a reference point on top of the levee on the North West corner of the Delta Pond. This reference was used as the occupy point for the duration of the survey. A second reference point was also surveyed on the North East corner of the concrete footing for the catwalk to the ponds outlet controls. A third reference point was surveyed on the West side of the Guerneville Rd Bridge at the USGS stream gaging station. These three points serve as reference points for future surveys, or as stationary benchmarks for post processing of data. All points were recorded using a Topcon Hyperlite Plus Real Time Kinematic (RTK) survey unit that uses a global positioning system. This unit was set to record points with an accuracy of ±0.43 inches (±1.0 cm), relative to the benchmarks used. The unit was also programmed to record an average of no less than three satellite readings for each point recorded. The survey of the channel was completed with the use of a boat and by wading, and the survey of the Laguna area was completed by a combination of boat travel and walking. The pond area to the West of the Laguna, as well as the field to the North of Santa Rosa Creek, and the Delta Pond area were all accessed by foot. Certain locations where access was limited due to brush cover were examined on the ground and local topography noted for use in construction of the final map (Figure 2). A total of eight hundred and eighty two points were taken over the survey area.

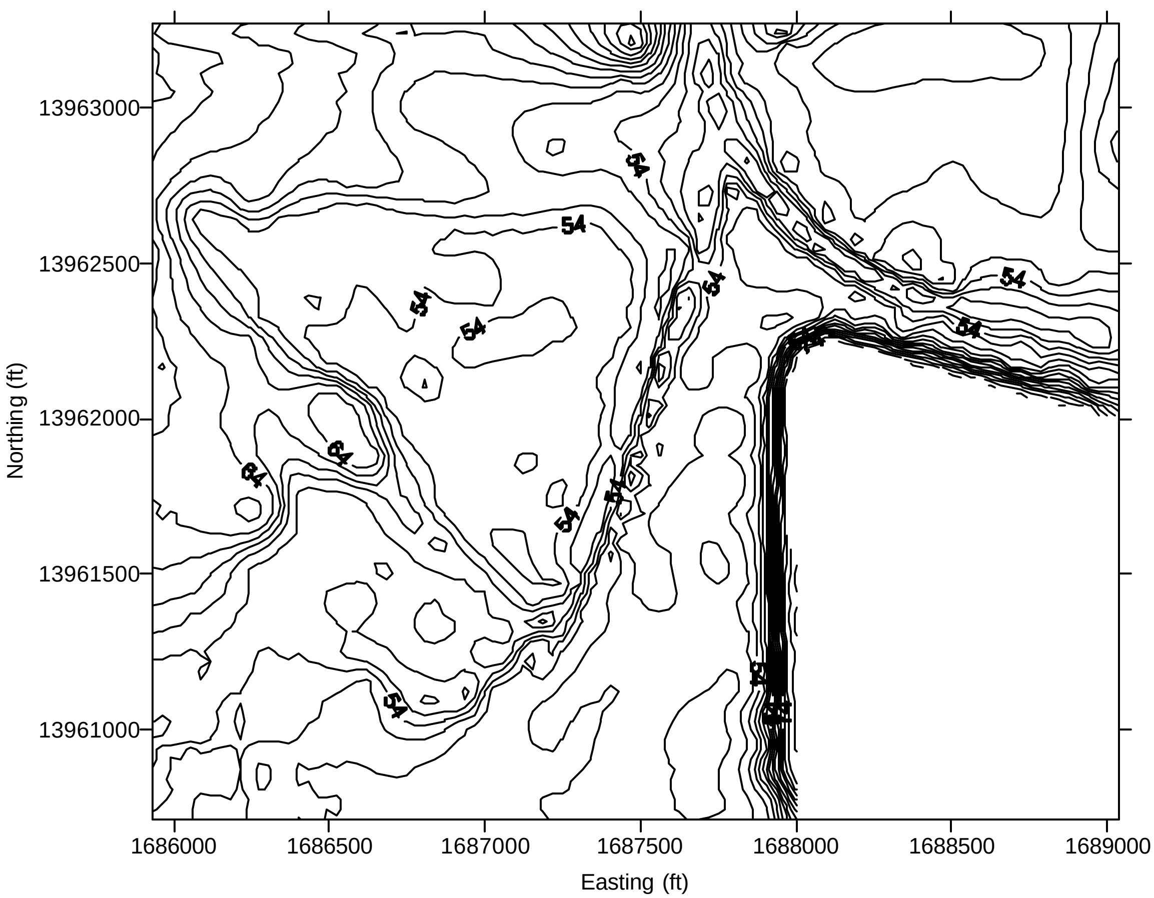



**Figure 2. Project area topographic map (elevations in feet mean sea level (msl))**

This topographic data was used in a preprocessor program, RMAGEN (King, 2004b), to construct the numerical mesh for use in RMA-2 based and RMA-11. RMAGEN assigns spatial information to each node within the mesh (x-y location and elevation), interpolating values from the topographic description. The mesh consists of triangular and quadrilateral elements of variable size and configuration. A triangular element consists of six nodes – three at the vertices and 3 mid-side nodes. Similarly, quadrilateral elements consist of eight nodes. The model mesh consists of over 2800 nodes forming 1,028 triangular and quadrilateral elements (Figure 3). Channels and the discharge location were represented with additional resolution in the finite element mesh.

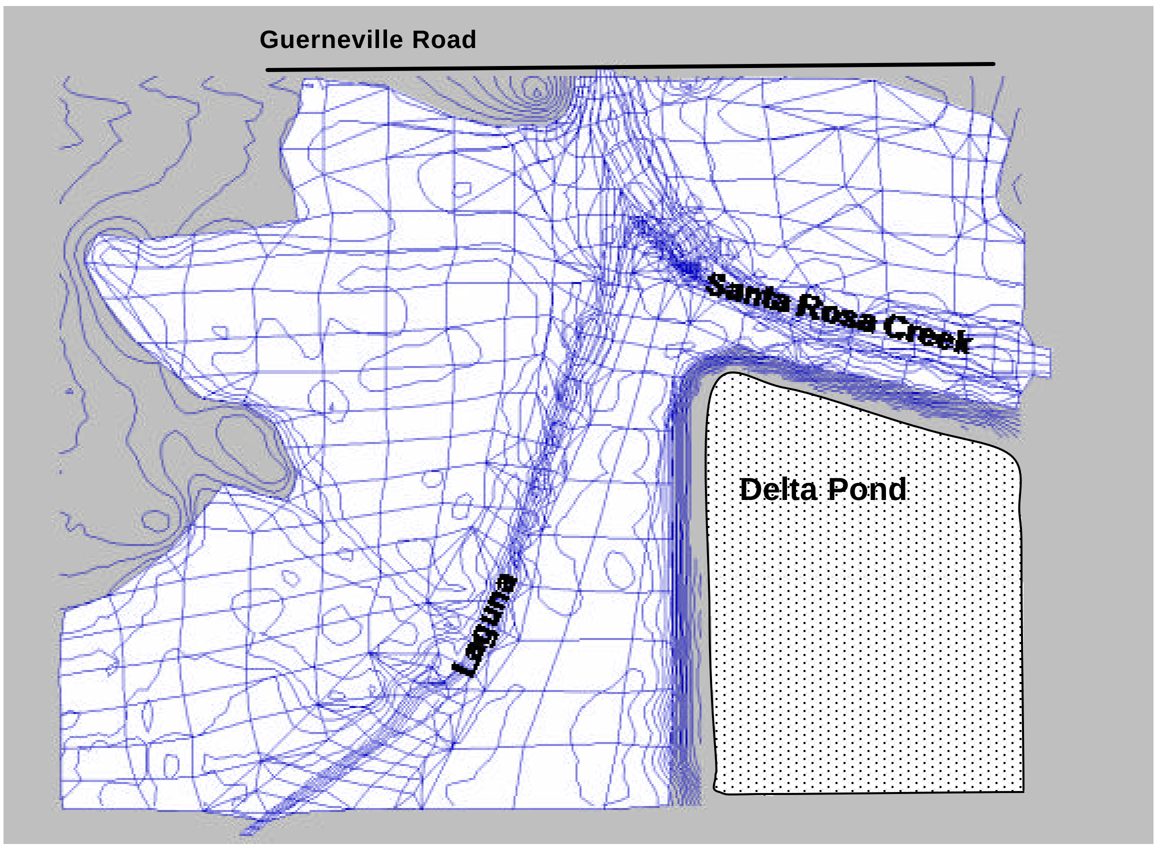



**Figure 3. RMA2 Finite Element Mesh**

Inflows were assumed for several flow rates consistent with combined flows for Santa Rosa Creek at Willowside (USGS 11466320), Laguna de Santa Rosa near Sebastopol (USGS 11465750), and any assumed discharge from Delta Pond. Outflow leaving the modeling domain at Guerneville Road Bridge was calculated as a mass balance – equal to all inflows.

A stage-discharge relationship (Figure 4) was constructed using the aforementioned gages and the stage gage for Laguna de Santa Rosa near Graton (at Guerneville Road) (USGS 11466500). The USGS stage gage at Guerneville Road does not record data below 55.0 feet msl. Thus from 51.0 to 55.0 feet msl, a 2nd order polynomial is used to represent the stage-flow relationship. The lower bound of 51.0 feet msl was based on field observations during the September 2007 when stage was approximately 51.5 feet msl and flow was estimated to be less than a few cfs at Guerneville Road. The upper bound of this relationship (55.0 feet msl) corresponds to a flow of approximately 250 cfs. From 55.0 to 70.0 feet msl, a linear regression based on the combined flows of USGS at Willowside (Santa Rosa Creek) and USGS at Sebastopol (Laguna), and USGS near Graton (Guerneville Bridge) is used for stage. This relationship shows increasing scatter above approximately 60.0 feet msl. This scatter reflects backwater conditions in the Laguna in response to stage in the Russian River during high flow events. Examining conditions when the Russian River at Guerneville is above 20,000 cfs suggests that the Laguna begins to be affected by backwater somewhere around elevation 60.0 feet msl. The point identified on the figure within an oval fall below the linear regression line, indicating that for similar stage readings, outflow from the Laguna at Guerneville Road are lower. The flow at the upper limit of the linear regression relationship (70.0 feet) corresponds to approximately 7000 cfs. From 70 to 75 feet, linear representation is used between 7000 cfs (the maximum observed stage from USGS records) and 28,500 cfs at a stage of 75 feet msl based on FEMA 100 year flood stage projections (FEMA 1991, 1995). A linear relationship between stage and flow was assumed due to limited data.

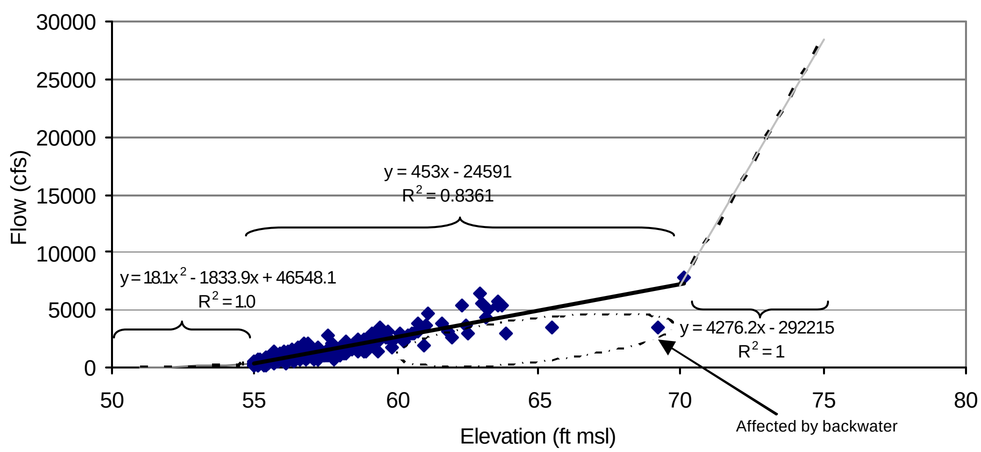



**Figure 4. Laguna de Santa Rosa at Guerneville Road stage-discharge relationship**

Channel roughness was varied for the channel and floodways. Manning roughness values for elements in channel areas (Laguna and Santa Rosa Creek) were set at 0.05, while elements located in the over bank floodway areas were set at 0.25 (UC Davis, 1995). Horizontal eddy coefficients for the two-dimensional simulation used fixed constant values of 0.001 for x and y coefficients for all elements.

## *MODEL REFINEMENT*

To manage discharge compliance with receiving water quality considerations a methodology was developed wherein receiving water flow and quality and discharge water quality are used to identify a discharge quantity while remaining in compliance and then verify compliance. To complete this task, the RMA-2 and RMA-11 models were applied over a wide range of receiving water flows and discharge rates. RMA-2 was used to define the zone of initial dilution (ZID) and RMA-11 was employed to identify a dilution factor (DF) for a full range of receiving water and discharge flow conditions. Using this information with receiving water quantity and quality, discharge quality, and receiving water compliance criteria, a discharge can be calculated. The process is depicted graphically in Figure 5, and the steps outlined in detail below.

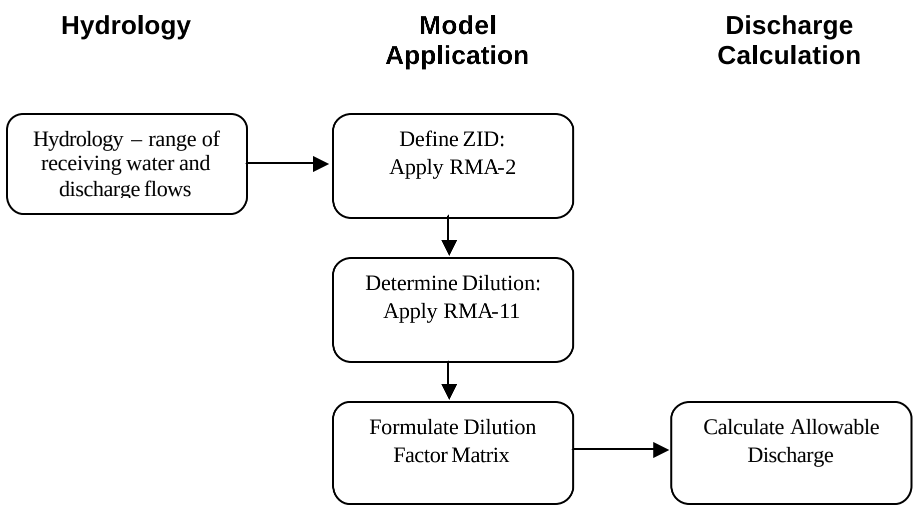



**Figure 5. Schematic of process to develop discharge compliance calculator**

### *Hydrology*

The hydrologic parameters consisted of receiving water flow and discharge. Modeled receiving water flows ranged from approximately 10 cfs to 5000 cfs at Guerneville Road Bridge and discharge rates assessed under these conditions ranged from 5 cfs (3.23 mgd) to 120 cfs (77.6 mgd). Laguna and Santa Rosa Creek flows were assumed equal in each case based on field observations (Figure 6). For flow rates less than approximately 400 cfs in Santa Rosa Creek or Laguna (combined flow of 800 cfs at Guerneville Road), the associated water levels resulted in the streams remaining within their respective channels (i.e., minimal over bank flow). Flows in excess of 400 cfs in the two streams results in over bank flows and contributions to Santa Rosa Creek from the Laguna at the outfall.

Thus, two independent discharge conditions were assessed: for flows below 400 cfs, discharges and associated mixing were assessed based on conditions in Santa Rosa Creek, and for discharges above 400 cfs over bank flow (flows crossing the floodplain) and entering the Santa Rosa Creek channel from the Laguna were explicitly incorporated in the two-dimensional model representation. Differentiating these two conditions was important in the analysis approach because at flows less than 400 cfs in Santa Rosa Creek, left bank attachment of the discharge occurred downstream of the outfall. For flows in excess of 400 cfs, contributions from the Laguna effectively displaced the discharge plume off of the left bank and minimal bank attachment occurred. Both of these conditions are depicted in Figure 7.

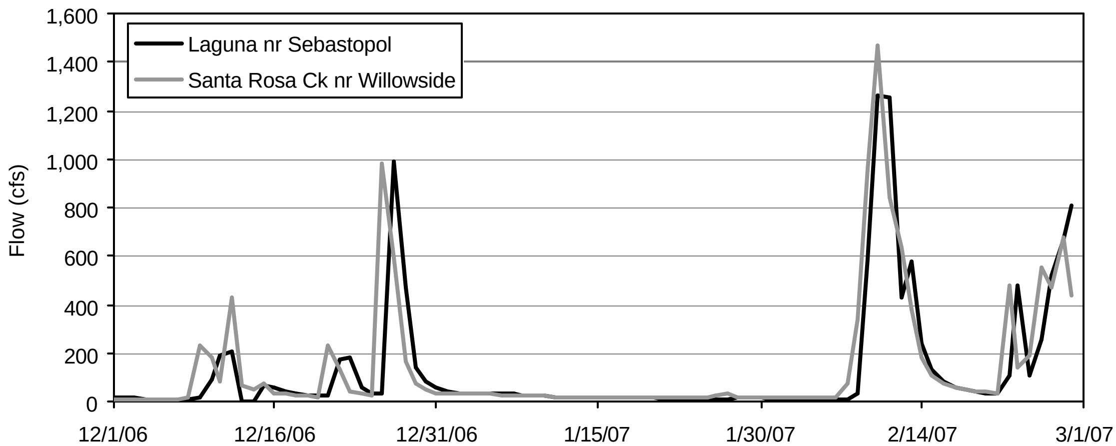



**Figure 6. Flows for December 2006 through February 2007 for Laguna near Sebastopol and Santa Rosa Creek at Willowside**

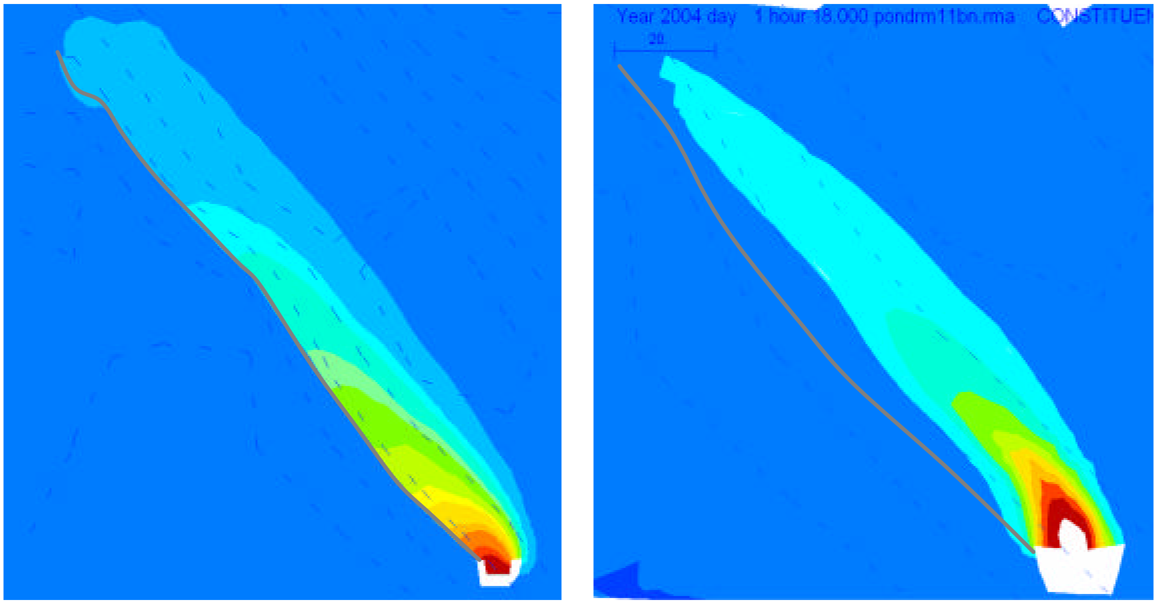



**Figure 7. Illustrative concentration gradients for (a) flows lower than 400 cfs in Santa Rosa Creek (bank attachment) and (b) flows greater than 400 cfs in Santa Rosa Creek with contributions from upstream Laguna flows (no bank attachment) [note: approximate shoreline in gray, figures are not on equal scales]**

### *Definition of the ZID*

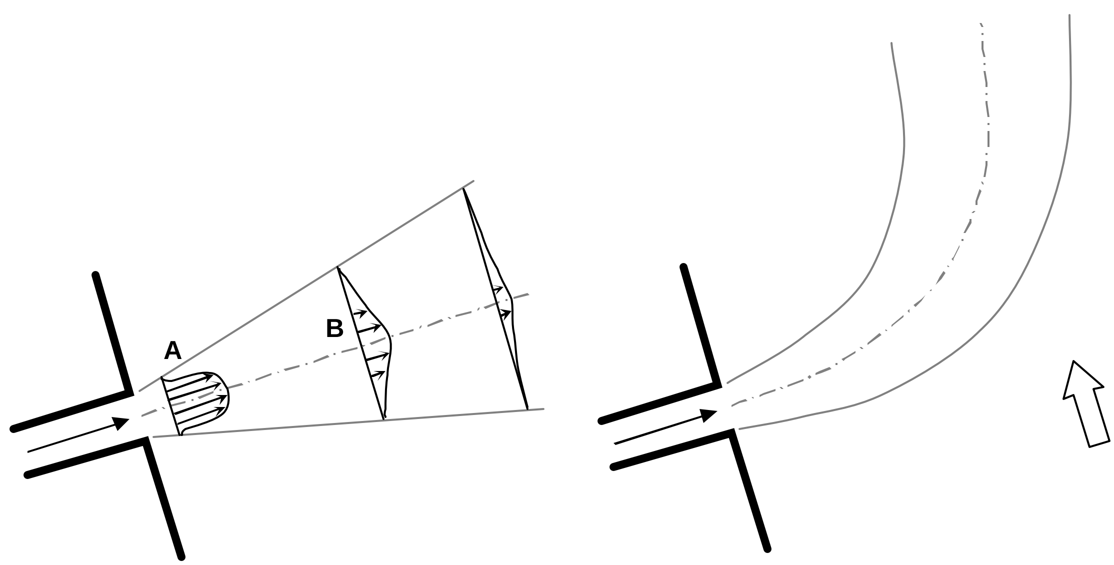
For an outfall discharge, the distance to leading edge of the ZID varied depending on the discharge and receiving water flow. For each combination of the simulated flows, the location of the edge of the ZID and the associated concentration was determined. Recall, the ZID is the defined as the extent of the receiving water where momentum induced velocity of the discharge ceases to produce significant mixing of the discharge. The effect of a discharge through the outfall forms a jet, wherein discharged water is mixed with ambient waters. For discharge in to still water (e.g., lake), jet undergoes an initial zone of establishment in the receiving water where the velocity profile is similar to the discharge (point A in Figure 8). Subsequently the jet attains a fully developed, symmetrical velocity profile (point B). When a discharge occurs in a cross current, the effect is a deflected jet (Figure 8). The results in significant distortion of the symmetry apparent in the discharge to a still water body. Discharge into a cross current results in considerably higher rates of ambient water entrainment into the discharge jet, resulting in higher dilution rates than for a discharge into still water. Jirka et al (1975) identify a criteria for transition from near field (jet conditions) to far field conditions in a cross flow as

$$\frac{u_c}{U_o - u_a \cos\theta} < 0.1 \qquad (1)$$

and

$$\frac{u_c}{u_a} < 1.0 \qquad (2)$$

Where $u_c$ is the jet centerline velocity, $u_a$ is the receiving water velocity, $U_o$ is the initial jet velocity at the outfall, and $q$ is the angle between the centerline of the jet and the dominant receiving water flow direction. In general, when the jet has deflected considerably ($\theta$ approaching $90^o$) the impacts of the ambient current in deflecting the jet are minimized, and Jirka et al identify that at approximately 10% of initial flow velocity near field momentum effects would largely be dissipated (equation 1). Coupled with this would be criteria that the jet centerline velocity would be less than the ambient current in the receiving water (equation 2).




(a) Discharge into still water

(b) Discharge into a cross current

**Figure 8. Discharge into (a) still water and (b) a cross current**

Because of the variable velocity distribution in the receiving waters of Santa Rosa Creek, such equations are not readily applied to the large number of discharge and receiving water conditions analyzed. To assess discharge conditions in the Laguna, these theoretical concepts were applied to direct comparison of simulated velocities wherein local velocities under discharge were compared to a base case (no discharge). Velocity vector magnitude and direction as well point velocities were examined to determine when

$u_c$ approached $u_a$, and to examine where $q$ approaches zero (Figure 9). To assist in these analyses, other useful model data were used, such as the backwater formed by the jet (Figure 9). These information and graphical model output from RMA-2 were used to identify the ZID as shown in Figure 10 and Figure 11.

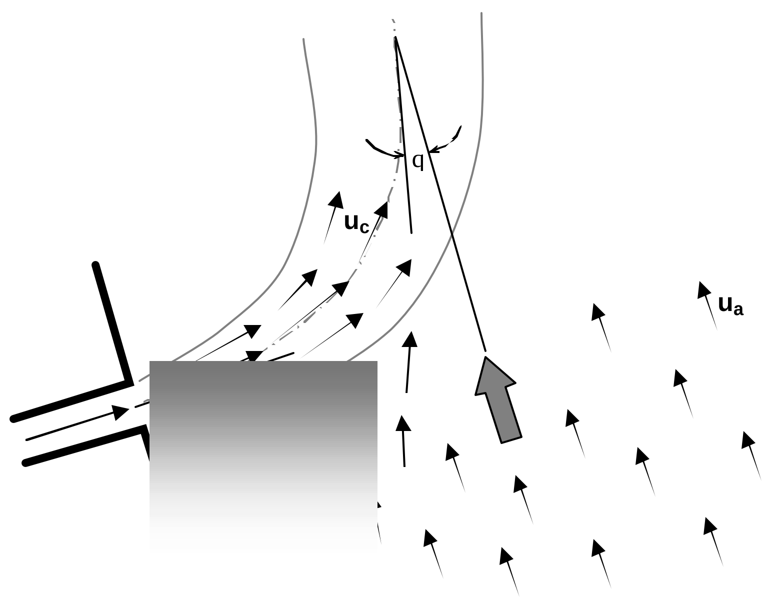



**Figure 9. Hypothetical velocity distribution and backwater (in grey) associated with a discharge into a cross current**

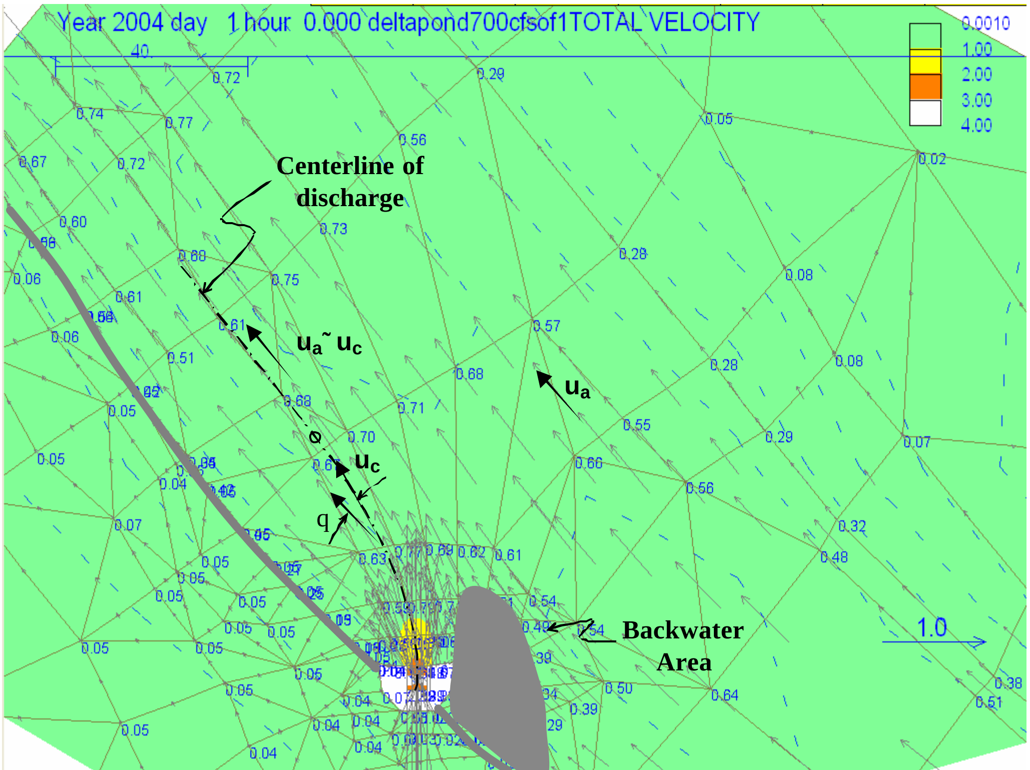



**Figure 10. Example RMA-2 velocity vector field showing ambient velocity (*$u_a$*), centerline jet (discharge) velocity (*$u_c$*), angle between ambient and centerline velocity (*q*), and location of backwater (gray area) used in determining ZID location**

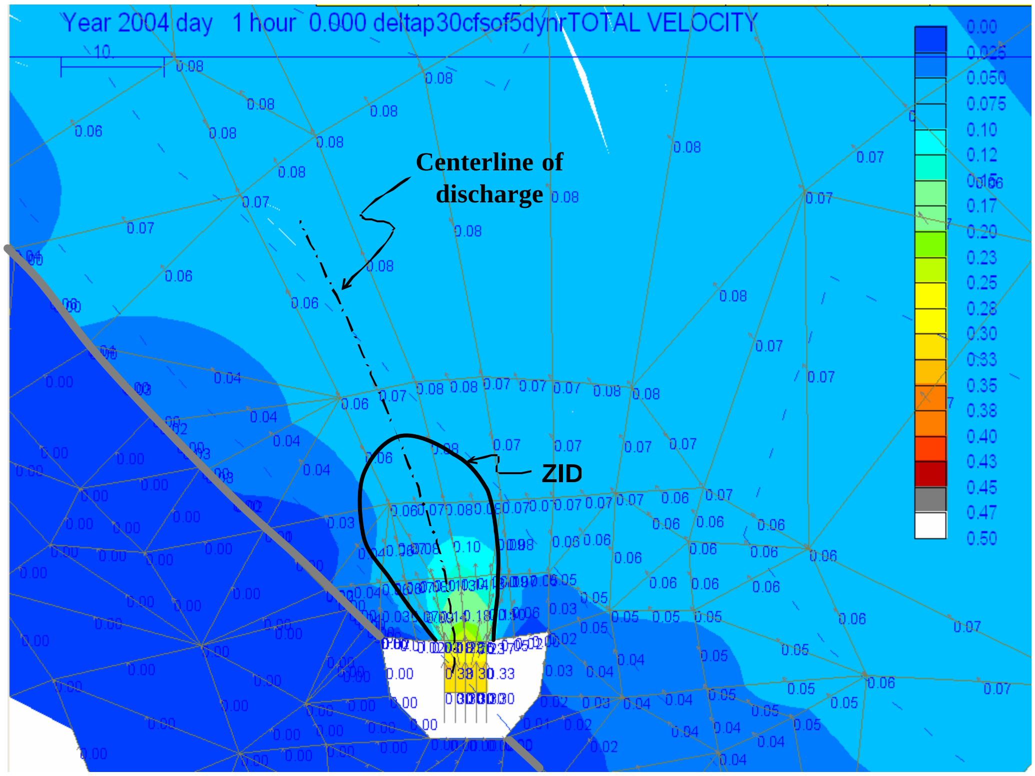



**Figure 11. Outfall ZID extend for a 5 cfs discharge into a 30 cfs receiving water flow**

### *Determination of Dilution*

To determine the dilution at the ZID for a range of combinations of receiving water flows and discharges, RMA-11 was applied using a conservative constituent to establish dilution. As noted above, for Santa Rosa Creek flows below approximately 400 cfs, discharges tended to attach to the left shoreline creating an asymmetrically distribution of concentrations about the center line of the discharge. To identify a representative dilution condition the average of two locations was applied: the concentration at the edge of the ZID at (a) the centerline of the discharge jet and (b) the highest concentration identified along the edge of the ZID (which was consistently located along the shoreward edge of the ZID) (Figure 12). This approach provided a conservative estimate to be applied to a large number of simulations.

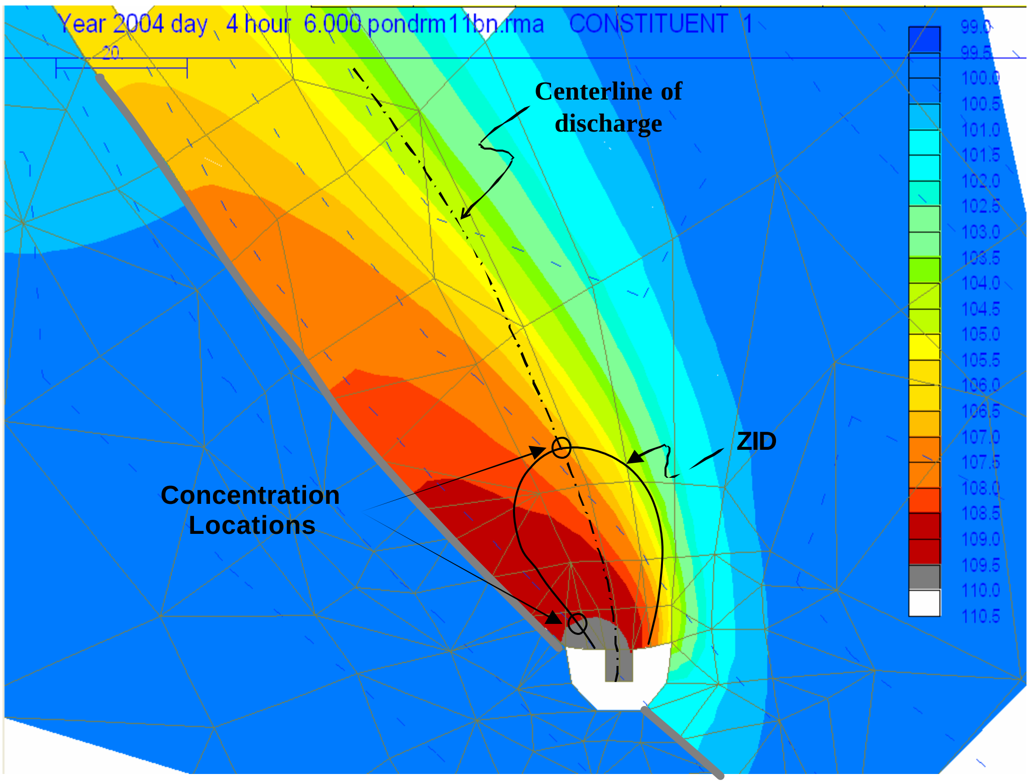



**Figure 12. Outfall ZID Boundary Example for Bank Attachment Case**

For conditions when flows in Santa Rosa Creek were in excess of 400 cfs, bank attachment was absent due to contributing flows from the Laguna as well as upstream Santa Rosa Creek over bank flows. Under these conditions, the distribution was largely symmetrical around the centerline of the ZID. In this case, dilution was determined based on the centerline concentration of the discharge at the edge of the ZID (Figure 13).

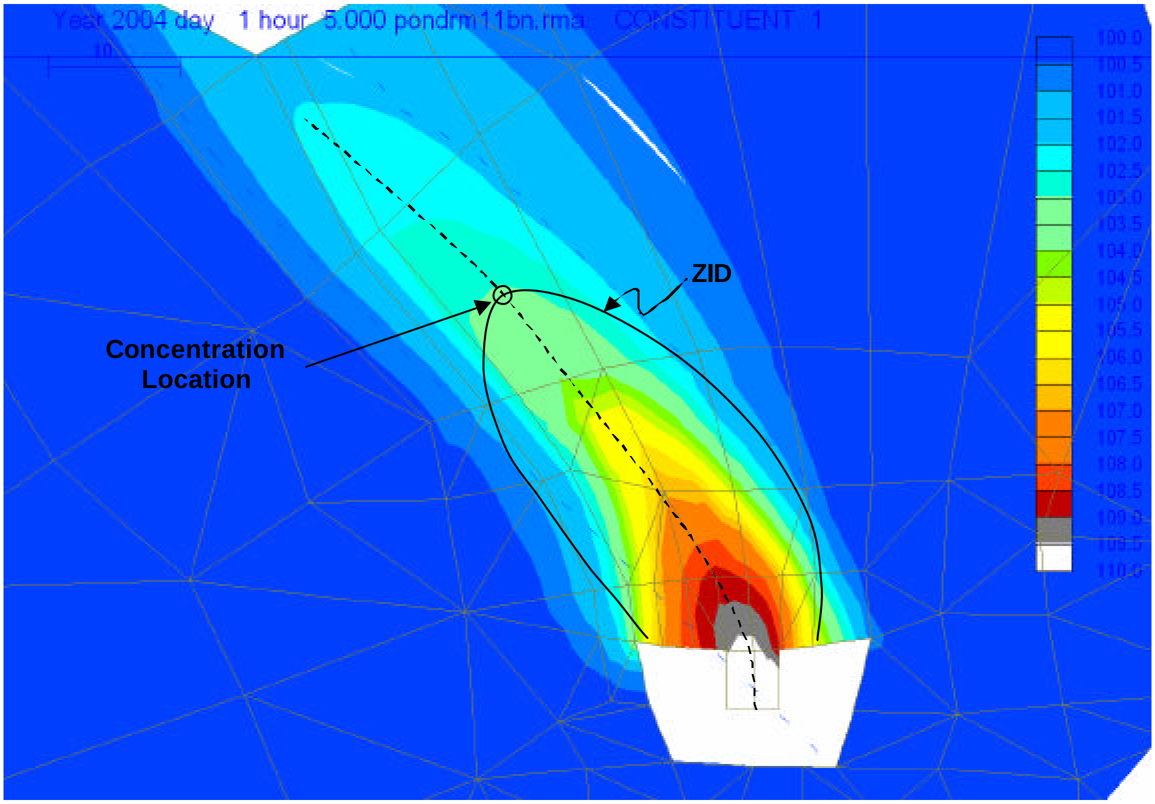



**Figure 13. Outfall ZID Boundary Example for flows higher than 400 cfs in Santa Rosa Creek**

To determine dilution downstream of the bank outfall, discharge flow rate was limited to 120 cfs, the approximate maximum discharge capacity from the existing Delta Pond facilities. The receiving water flows ranged up to 5000 cfs and are divided into two categories: below 400 cfs and above 400 cfs, the latter category to assess over bank flow conditions in the Santa Rosa Creek and Laguna confluence region. Basing dilution on the aforementioned approach (i.e., Figure 12 and Figure 13), the appropriate matrix values for discrete flows were compiled (Table 1 and Table 2). For all simulations, a conservative constituent is modeled, with receiving water having 100 units (e.g., mg/l) of concentration and discharge having a concentration of 110 units.

**Table 1. Concentrations at edge of ZID for selected discharge and receiving water flows below 400 cfs in Santa Rosa Creek**

| Discharge Flow (cfs) | Receiving Water Flow (cfs) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***10*** | ***20*** | ***30*** | ***50*** | ***70*** | ***90*** | ***100*** | ***150*** | ***200*** | ***300*** | ***400*** | ***500*** | ***600*** | ***700*** | ***800*** |
| ***120*** | 110.0 | 110.0 | 110.0 | 110.0 | 110.0 | 110.0 | 110.0 | 110.0 | 110.0 | 108.0 | 108.0 | 107.5 | 107.5 | 107.0 | 107.0 |
| ***110*** | 110.0 | 110.0 | 110.0 | 110.0 | 110.0 | 110.0 | 110.0 | 110.0 | 110.0 | - | - | - | - | - | - |
| ***100*** | 110.0 | 110.0 | 110.0 | 110.0 | 110.0 | 110.0 | 110.0 | 110.0 | 108.0 | 108.0 | 108.0 | - | - | 107.0 | 107.0 |
| ***90*** | 110.0 | 110.0 | 110.0 | 110.0 | 110.0 | 110.0 | 110.0 | 110.0 | 108.0 | 108.0 | 108.0 | - | - | - | - |
| ***80*** | 110.0 | 110.0 | 110.0 | 110.0 | 110.0 | 110.0 | 110.0 | 110.0 | - | - | - | - | - | - | - |
| ***70*** | 110.0 | 110.0 | 110.0 | 110.0 | 110.0 | 110.0 | 110.0 | 109.0 | 108.0 | 108.0 | 108.0 | 108.0 | 108.0 | 106.5 | 106.5 |
| ***60*** | 110.0 | 110.0 | 110.0 | 110.0 | 110.0 | 110.0 | 110.0 | 108.5 | - | - | - | - | - | - | - |
| ***50*** | 110.0 | 110.0 | 110.0 | 110.0 | 110.0 | 110.0 | 108.0 | 108.0 | 108.0 | 107.0 | 109.0 | - | - | - | - |
| ***40*** | 110.0 | 110.0 | 110.0 | 110.0 | 110.0 | 108.0 | 108.0 | - | - | - | - | - | - | - | - |
| ***30*** | 110.0 | 110.0 | 110.0 | 110.0 | 108.5 | 108.0 | - | - | 108.0 | - | - | - | - | - | - |
| ***20*** | 110.0 | 110.0 | 110.0 | 109.0 | 108.5 | 108.0 | 108.0 | - | 108.0 | 107.0 | 107.0 | 107.0 | 106.5 | 106.5 | 106.5 |
| ***15*** | 110.0 | 110.0 | 109.5 | 109.0 | 109.0 | 108.0 | - | - | - | - | - | - | - | - | - |
| ***10*** | 110.0 | 110.0 | 109.5 | 109.0 | 108.0 | 108.5 | 108.0 | 107.0 | 106.5 | - | - | - | - | - | - |
| ***5*** | 110.0 | 110.0 | 109.0 | 107.5 | 106.5 | 106.5 | 106.0 | 105.5 | 105.0 | 105.0 | 105.0 | 104.5 | 104.0 | 103.5 | 103.5 |

**Table 2. Concentrations for selected discharge and receiving water flows above 400 cfs in Santa Rosa Creek**

| | | Receiving Water Flow (cfs) | | | | | |
|---|---|---|---|---|---|---|---|
| | | ***800*** | ***1000*** | ***1500*** | ***2000*** | ***3000*** | ***5000*** |
| **Discharge Flow (cfs)** | ***120*** | 107.3 | 106.8 | 105.0 | 104.6 | 103.5 | 102.3 |
| | ***90*** | 106.9 | 106.4 | 104.7 | 104.2 | 103.2 | 102.1 |
| | ***50*** | 106.2 | 105.6 | 104.1 | 103.6 | 102.7 | 101.6 |
| | ***20*** | 105.0 | 104.4 | 103.2 | 102.6 | 102.0 | 101.0 |
| | ***5*** | 103.2 | 102.5 | 101.8 | 101.1 | 100.8 | 100.0 |

All possible combinations of discharge and receiving water flows were not evaluated (omitted combinations are denoted with a "-" in the above tables, and gray cells denote no dilution at the ZID). However, a sufficient number of simulations were completed to develop regression relationships for each receiving water flow. The concentrations for all possible discharge flows (1 through 120 cfs in one cfs increments) were determined using a regression equation with discharge flow as the independent variable and concentration as the dependent variable. A power equation form was used and the results presented in Table 3.

**Table 3. Regression equations for discharges for Santa Rosa Creek flows less than or equal to 400 cfs**

| Receiving Water Flow (cfs) | | Regression Equation for Concentration in Receiving Water[2] | R-Square |
|---|---|---|---|
| Total[1] | Santa Rosa Creek Only | | |
| 10 | 5 | 110.0 | - |
| 20 | 10 | 110.0 | - |
| 30 | 15 | 108.26*($D_i$^0.00442) | 0.87 |
| 50 | 25 | 106.00*($D_i$^0.01015) | 0.78 |
| 70 | 35 | 105.09*($D_i$^0.01083) | 0.69 |
| 90 | 45 | 106.35*($D_i$^0.00496) | 0.35 |
| 100 | 50 | 105.56*($D_i$^0.00656) | 0.57 |
| 150 | 75 | 104.01*($D_i$^0.01046) | 0.94 |
| 200 | 100 | 104.41*($D_i$^0.00826) | 0.73 |
| 300 | 150 | 103.73*($D_i$^0.00881) | 0.92 |
| 400 | 200 | 103.91*($D_i$^0.00906) | 0.75 |
| 500 | 250 | 103.35*($D_i$^0.00944) | 0.83 |
| 600 | 300 | 102.49*($D_i$^0.01120) | 0.89 |
| 700 | 350 | 102.47*($D_i$^0.00951) | 0.82 |
| 800 | 400 | 101.18*($D_i$^0.01225) | 0.96 |

[1] combined Laguna and Santa Rosa Creek flow (equals two times Santa Rosa Creek flow) at Guerneville Road. The regression equations are based on "total" flow at Guerneville road to accommodate over bank flows of 400 cfs, (tabulated regression equations for over 400 cfs included in spreadsheet calculator).

[2] Downstream concentration is based on a receiving water concentration of 100.0, i.e., for Santa Rosa Creek flows less than 10 cfs, there is no dilution at the edge of the ZID because the downstream value is 110, which is equal to the discharge concentration. At increasing Santa Rosa Creek flows, dilution at the ZID increases.

### *Dilution Factor*

The dilution factor for a given discharge is of primary interest to represent mixing for the discharge compliance framework. Dilution factor, DF, is defined as

$$DF = \frac{Q_{receivingwater} + Q_{discharge}}{Q_{discharge}} \tag{3}$$

and can be interpreted as the inverse of dilution. Thus, given a receiving water quantity and a DF, discharge can be determined to meet a specific water quality conditions downstream of the outfall (presented below). The first step was creating a matrix or table of dilution factors for the range of receiving water and discharge flows (Table 4).

**Table 4. Example Discharge Flow, Receiving Water Flow, Dilution Factor Matrix.**

| | | Receiving Water Flow | | | |
|---|---|---|---|---|---|
| | | $Q_{R1}$ | $Q_{R2}$ | … | $Q_{Rn}$ |
| Discharge Flow | $Q_{D1}$ | $DF_{1,1}$ | $DF_{2,1}$ | … | $DF_{n,1}$ |
| | $Q_{D2}$ | $DF_{1,2}$ | $DF_{2,2}$ | … | $DF_{n,2}$ |
| | ⋮ | ⋮ | ⋮ | ⋱ | ⋮ |
| | $Q_{Dm}$ | $DF_{1,m}$ | $DF_{2,m}$ | … | $DF_{n,m}$ |
| R- receiving water flow rate<br>D – discharge flow rate | | | | | |

Concentrations from the regression equations were used to determine these edge-of-ZID dilution factors. Receiving water concentration ($C_{ReceivingWater,Rj}$) was assumed 100 and the discharge concentration ($C_{Discharge,Di}$) was assumed 110, regardless of the flow rates. Concentration at the edge of the ZID ($C_{ZIDij}$) was determined from the description of the ZID identified using RMA-2 and the associated concentration distribution produced by RMA-11. The dilution factor ($DF_{ZID,Rj,Di}$) is then determined based on

$$DF_{ZID,Rj,Di} = \frac{C_{Discharge,Di} - C_{RecievingWater,Rj}}{C_{ZID_{ij}} - C_{ReceivingWater,Rj}} \quad (4)$$

The concentrations at the edge of the ZID is known for all discharges (from the regression equations), and the corresponding dilution factors are calculated and tabulated (Table 5). Note that the minimum allowable dilution factor is 1.0 (corresponds to a ZID concentration of 110, the same as the discharge, i.e., no dilution) and the maximum allowable dilution factor is 1000.0 (corresponding to a ZID concentration of 100.01, nearly the same as the receiving water). The maximum allowable dilution factor must be limited such that $C_{ReceivingWater,Rj}$ does not equal $C_{ZID,ij}$.

**Table 5. Sample Dilution Factor Table for Outfall Discharge.**

| | | Total Receiving Water Flow (cfs) | | | | | |
|---|---|---|---|---|---|---|---|
| | | *10* | *20* | *30* | … | *700* | *800* |
| Discharge Flow (cfs) | *1* | 1.00 | 1.00 | 1.21 | … | 4.05 | 4.05 |
| | *2* | 1.00 | 1.00 | 1.16 | … | 3.18 | 3.18 |
| | *3* | 1.00 | 1.00 | 1.14 | … | 2.82 | 2.82 |
| | ⋮ | ⋮ | ⋮ | ⋮ | ⋱ | ⋮ | ⋮ |
| | *119* | - | - | - | … | 1.38 | 1.38 |
| | *120* | - | - | - | … | 1.38 | 1.38 |

### *Allowable Discharge*

The dilution factor matrix is used to determine the allowable discharge for a given set of receiving water flow and concentrations, discharge concentration, and receiving water criteria for temperature, dissolved oxygen, turbidity, pH, or other constituent. Generically,

$$DF_{Ck,Rj,Di} = \frac{C_{Discharge,Di} - C_{RecievingWater,Rj}}{C_{Criteria,k} - C_{ReceivingWater,Rj}} \quad (5)$$

The discharge concentration ($C_{Discharge,Di}$) any discharge, *i*, will be known from field observations, along with the receiving concentration at flow, *j* ($C_{ReceivingWater,Rj}$). Further, the receiving water criteria concentration for constituent *k* at the edge of the ZID ($C_{Criteria,k}$) is based on current permit criteria (Table 6). Subsequently, the dilution factor for discharge flow *i*, receiving water flow *j*, and concentration criteria *k* ($DF_{Ck,Rj,Di}$) can be calculated using equation 5.

**Table 6. Current permit criteria for temperature, dissolved oxygen, turbidity and pH**

| Category | Criteria |
|---|---|
| Temperature | ▪ When the receiving water is below 58°F, the discharge shall cause an increase of no more than 4°F in the receiving water, and shall not increase the temperature of the receiving water beyond 59°F. No instantaneous increase in receiving water temperature shall exceed 4°F at any time.<br>▪ When the receiving water is between 59°F and 67°F, the discharge shall cause an increase of no more than 1°F in the receiving water. No instantaneous increase in receiving water temperature shall exceed 1°F at any time. |
| Dissolved Oxygen | ▪ When the receiving water DO is below 7 mg/L, the discharge shall not cause the DO to decrease.<br>▪ When the receiving water DO is greater than 7 mg/L, the discharge shall not cause the DO to decrease below 7 mg/L. |
| Turbidity | ▪ The discharge shall not increase the turbidity by more than 20%. |
| pH* | ▪ Discharge shall not increase the pH to above 8.5 or decrease pH to below 6.5, and shall not degrade conditions if receiving waters are outside this range. Discharge shall not change the pH by more than 0.5 units. |
| * The time through the mixing zone is estimated to be short – on the order of tens of seconds. Temperature, dissolved oxygen, turbidity, and pH are treated as conservative constituents. | |

With a known dilution factor and receiving water flow, the allowable discharge can be determined from the tabulated DF values. Specifically, allowable discharge is determined by linearly interpolating between the two nearest values:.

$$QA_{Di} = Q_{i+1} - \left(Q_{i+1} - Q_{i-1}\right)\left(\frac{DF_{i+1} - DF_{Ck,Rj,Di}}{DF_{i+1} - DF_{i-1}}\right) \quad (6)$$

Where, $QA_{Di}$ is the calculated allowable discharge for the known dilution factor ($DF_{Ck,Rj,Dj}$). $Q_{i+1}$ and $Q_{i-1}$ are the flow between which must be interpolated. Likewise, $DF_{i+1}$ and $DF_{i-1}$ are the corresponding dilution factors between which the final value is interpolated.

For all flows (above and below 400 cfs) receiving water flow concentration is assumed to be Santa Rosa Creek upstream of the outfall. This is directly applicable for flows below 400 cfs. In the case where discharge would increase the flow to over 400 cfs below the outfall, tabulated dilution factors for flows below 400 cfs are applied. This approach is deemed conservative because the tabulated dilution factors for flows above 400 cfs are considerably larger (i.e., more dilution), in part due to flows from the Laguna proper commingling with Santa Rosa Creek upstream of the discharge point. Additional field observations are recommended to determine if there is additional discharge capability.

## *DISCHARGE OPERATIONS AND COMPLIANCE VERIFICATION*

This section describes the method to be used to determine the quantity of water to be discharged each day in compliance with receiving water limits and the method used to verify that discharge was indeed in compliance. Successful implementation of the framework depends on the collection of data characterizing the quality of recycled water and receiving water at locations upstream of the discharge. Water quality monitoring equipment of a similar nature to that used currently should be deployed and data relayed daily or on a "real time" basis to Subregional staff to provide the basis for operational decisions. The protocol for converting continuous monitoring data into the basis for operations decisions will reflect local conditions.

Water quality conditions generally correlate to flow conditions over short periods of time, e.g., day-to-day. Thus, forecast of water quality conditions for any particular day is based upon receiving water flow regime (Santa Rosa Creek and Laguna near Sebastopol). If flow conditions in the receiving water are relatively stable (i.e., no storm events or other large changes in base flow), water quality conditions for the particular parameter from the previous 24-hours are assumed for the subsequent 24-hours and entered into the spreadsheet to calculate discharge rate or volume. If flow conditions in the receiving water are variable, such as during or after a storm (e.g., ascending or descending hydrograph), additional information will be considered in the discharge volume calculation. Previous day water quality conditions will be employed as under the stable flow regime; however, trends over the previous 24-hours in flow and water quality (of both receiving water and discharge) are also considered using real time data. The advanced hydrologic prediction (AHP) service, operated by the National Weather Service, provides a multiple day forecast of stage and flows in the Russian River at Healdsburg and Guerneville (see Appendix). The AHP forecast, coupled with real time flow and stage in the Laguna and Santa Rosa Creek, will provide the necessary insight to determine the appropriate discharge.

A spreadsheet has been established as a tool to determine the quantity to be discharged in compliance with receiving water limits and to retrospectively verify compliance. The specific water quality data used to determine discharge volume and compliance varies by constituent in addition to water quality variability. The constituent-specific approach for stable and variable water quality conditions is described below and in Table 7.

**Table 7. Water quality parameters and compliance water quality**

| Water Quality Parameter | Water Quality Metric | | |
|---|---|---|---|
| | Stable Flow Regime [a,b] | | Variable Flow Regime [a,c] |
| | Receiving Water | Discharge | |
| Temperature | Paired hourly data from previous day values (paired with discharge) | Paired hourly data from previous day values (paired with receiving water) | Calculate as per stable flow regime coupled with assessment of last 24 hour period water quality trend. |
| Dissolved Oxygen | Paired hourly data from previous day values (paired with discharge) | Paired hourly data from previous day values (paired with receiving water) | Calculate as per stable flow regime coupled with assessment of last 24 hour period water quality trend. |
| Turbidity | Average based on previous day values | Average based on previous day values | Calculate as per stable flow regime coupled with assessment of last 24 hour period water quality trend. |
| pH | Paired hourly data from previous day values (paired with discharge) | Paired hourly data from previous day values (paired with receiving water) | Calculate as per stable flow regime coupled with assessment of last 24 hour period water quality trend. |

[a] Based on flow in Santa Rosa (USGS 11466320) Creek and the Laguna de Santa Rosa at Sebastopol (USGS 11465750). (all temperature, dissolved oxygen, turbidity, and pH metrics derived from 15-minute compliance monitoring data)

[b] These values are used to estimate discharge volume under stand flow conditions and to determine compliance under all conditions.

[c] These values are used solely to estimate discharge volume, not to determine compliance.

### *Temperature*

Compliance with the temperature limit described in Table 6 will be determined using hourly temperature and flow values created by averaging observed 15-minute values. The spreadsheet evaluates these 24 hourly data to determine if the temperature limit was exceeded at the edge of the ZID. If an exceedence occurred, this would be considered to be an exceedence (and thus possibly a violation) by RWQCB. In light of this compliance determination approach, the volume of water to be discharged should be estimated using hourly receiving water flow and temperature data for the preceding 24-hour period adjusted as necessary to reflect flow and/or temperature trends.

***Dissolved Oxygen***

Compliance with the dissolved oxygen limit described in Table 6 will be determined using hourly dissolved oxygen and flow values (created by averaging observed 15-minute values). The spreadsheet evaluates these 24 hourly data to determine if the dissolved oxygen was exceeded at the edge of the ZID. If an exceedence occurred, this would be considered to be an exceedence (and thus possibly a violation) by RWQCB. In light of this compliance determination approach, the volume of water to be discharged should be estimated using hourly receiving water flow and temperature data for the preceding 24-hour period adjusted as necessary to reflect flow and/or dissolved oxygen trends.

***Turbidity***

Compliance with the turbidity limit described in Table 6 will be based on the paired average daily turbidity and flow data. The daily average data are calculated using the observed 15-minute data from the water quality probes and flow gauges used in compliance monitoring. The spreadsheet evaluates the 24-hour average turbidity value to determine if the turbidity limit was exceeded at the edge of the ZID. In light of this compliance determination approach, the volume of water to be discharged should be estimated using daily turbidity and flow data from the preceding 24-hour period adjusted as necessary to reflect flow and/or turbidity trends..

***pH***

Compliance with the upper and lower pH limit described in Table 6 will be determined using hourly pH and flow values (created by averaging observed 15-minute values). The spreadsheet evaluates these 24 hourly data to determine if pH was exceeded at the edge of the ZID. If an exceedence occurred, this would be considered to be an exceedence (and thus possibly a violation) by RWQCB. In light of this compliance determination approach, the volume of water to be discharged should be estimated using hourly receiving water flow and pH data for the preceding 24-hour period adjusted as necessary to reflect flow and/or pH trends.

***Data Sources***

This section describes the source of water quality and flow data to be used to determine the quantity of water to be discharged each day in compliance with receiving water limits and to verify that discharge was indeed in compliance.

A water quality probe will be continuously deployed to collect water temperature, dissolved oxygen, turbidity, pH, and conductivity immediately above the outfall. For flows under 400 cfs in Santa Rosa Creek, this location will effectively represent Santa Rosa Creek conditions. For flows in excess of 400 cfs, flows from the Laguna will commingle with Santa Rosa Creek at the outfall, and this monitoring location will effectively capture the quality of the commingled flows. Thus, the full range of water quality conditions necessary for the spreadsheet will be reported from this single monitoring location.

No compliance criterion has been established for conductivity; however, the RWQCB requests that the City collect such data.

Effluent quality data from a water quality probe deployed in Delta Pond will be continuously deployed to collect water temperature, dissolved oxygen, turbidity, pH, and conductivity should be used to represent effluent quality in the discharge.

Flow data to be used in conjunction with the water quality observations are derived from two USGS gages located upstream of the Delta Pond discharge: Santa Rosa Creek at Willowside (USGS 11466320) and Laguna de Santa Rosa near Sebastopol (USGS 11465750). These are active gages that provide real time observations (e.g., 15 minute). Delta Pond discharge flow data will be obtained from the flow gages in the Pond outlet piping.

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# *APPENDIX*

## *WORKBOOK*

The compliance workbook consists of several worksheets. This worksheet provides a quick and transparent method for determining what discharge can be made for a combination of receiving water flows and quality, and discharge quality.

## *"START" SHEET*

The "Start" worksheet contains the instructions and user input fields, and the program (macro) launch button. There are two types of user-defined cells. The first type is the dashed-outlined white cells which contain values that are not likely to be changed between model runs. These are the units associated with the flow and concentrations. The second are the solid-outlined pink cells that contain the values the user can change for each model run. The pink cells specify the receiving water flow units, the allowable criteria slack, and the date of interest. The flow and concentration data are provided on the "InputData" worksheet.

Flow units must be in either million gallons per day (*mgd*) or cubic feet per second (*cfs*). If *mgd* is specified, then the spreadsheet model will convert the flow to *cfs*. The user should not change anything in the solid-dark-outlined green cells. These values are computed by the model or supplied from the user-provided input data.

The program (macro) consolidates the user-defined sub-hourly data into hourly data to evaluate temperature, dissolved oxygen, and pH, and daily average data for turbidity. The consolidated data are supplied to the model and the results are stored. At the end of a macro run, are 24 result data sets (one for each hour) are generated which include the calculated discharge criterion, maximum allowable flow, and limiting criteria. The temperature, dissolved oxygen, and pH input and output data can vary by hour, while the turbidity data are constant because a daily average input value is used. The macro reads the date of interest provided by the user and includes a check to verify that the date specified is available in the "InputData" set and is actually the date of interest to the user.

With the above data known, the spreadsheet model then determines the dilution factor (DF). The allowable discharge flow is then determined on the "Matrix_Outfall" sheet. The result is reported back to the "Start" sheet. The "Start" sheet also indicates which criteria or combination of criteria is binding. The results then indicate the amount of mixing that will occur due to the relative concentrations of the ambient water, discharge water, and criteria requirement.

### *"MATRIX_OUTFALL" SHEET*

The "Matrix_Outfall" sheet contains the data to be used by the model. These should not be changed unless the dilution factors are being updated. The matrix relates dilution factors to receiving water and discharge water flows. The model needs the pre-calculated dilution factor (on "Start" sheet) to determine the allowable discharge flow. The dilution factor is assumed to be linear between two points.

At some point the flow in Creek will top the banks and merge with flow from the Laguna. The breakpoint has been identified as 800 cfs (400 cfs in Santa Rosa Creek and 400 cfs in the Laguna). If the receiving water flow (Santa Rosa Creek) is below 400 cfs, the model uses the table of dilution factors from receiving water flows of less than 400 cfs even if identified discharge results in Santa Rosa Creek flows below the outfall greater than 400 cfs.

### *"CRITERIA" SHEET*

The "Criteria" worksheet contains the current permit (Permit) criteria for temperature, dissolved oxygen, and turbidity. The criteria are based on the requirements specified by the Permit and the allowable uncertainty (also termed slack) expected in monitoring the identified parameters. Such uncertainty results from instrument accuracy, instrument maintenance and calibration, placement in the stream, and other ambient conditions. This uncertainty or slack in monitoring data values is presented in **Error! Reference source not found.** Table 8 and amounts to 5 percent or less of the typical range for each constituent. For example, if the Permit criteria allows for a 60°F temperature and the slack is 0.5°C, then all ZID temperatures of 60.5°F or less would be within compliance.

**Table 8. Uncertainty (slack) for parameters included in the compliance worksheet**

| Constituent | Typical Range* | Uncertainty (Slack) |
|---|---|---|
| Temperature | 45 to >60°F | 0.5°F |
| Dissolved Oxygen | 3 to 13 mg/l | 0.5 mg/l |
| Turbidity | 1 to >100 NTU | 0.5 NTU |
| pH | 6.5-8.5 | 0.1 |

#### *Permit Criteria*

The spreadsheet model currently uses the Permit Criteria for temperature, dissolved oxygen, and turbidity. The criteria are as follows:

| Category | Criteria |
|---|---|
| Temperature | ▪ When the receiving water is below 58°F, the discharge shall cause an increase of no more than 4°F in the receiving water, and shall not increase the temperature of the receiving water beyond 59°F. No instantaneous increase in receiving water temperature shall exceed 4°F at any time.<br>▪ When the receiving water is between 59°F and 67°F, the discharge shall cause an increase of no more than 1°F in the receiving water. No instantaneous increase in receiving water temperature shall exceed 1°F at any time. |
| Dissolved Oxygen | ▪ When the receiving water DO is below 7 mg/L, the discharge shall not cause the DO to decrease.<br>▪ When the receiving water DO is greater than 7 mg/L, the discharge shall not cause the DO to decrease below 7 mg/L. |
| Turbidity | ▪ Discharge shall not increase the turbidity by more than 20%. |
| pH | ▪ Discharge shall not increase the pH to above 8.5 or decrease pH to below 6.5, and shall not degrade conditions if receiving waters are outside this range. Discharge shall not change the pH by more than 0.5 units. |

### *"INPUTDATA" SHEET*

The "InputData" worksheet is where the user specifies the sub-hourly flow and concentration values for the receiving and discharge waters. All of the data must be in the consistent units for each parameter (i.e., all temperature data must in either $^{o}$C or $^{o}$F). The time/date stamp must contain the month, day, year, and time of the data point (e.g., mm/dd/yyyy hh:mm) and be in Column *A*. The rest of the required data are receiving water flow (column *B*), temperature (column *C*), dissolved oxygen (column *D*), turbidity (column *E*), and pH (column *F*) and discharge water temperature (column *G*), dissolved oxygen (column *H*), turbidity (column *I*), and pH (column *J*).

The macro averages the 15-minute data (if applicable) into hourly data. For example, all data points corresponding to times after 01:00 and up to and including 02:00, are averaged and reported as the average 02:00 value. The first averaged value corresponds to 01:00 (which averages values corresponding between midnight and 01:00). The last averaged value corresponds to midnight (24:00) and averages values after 23:00 through 24:00.

The macro will only average the data corresponding to the date of interest specified by the user.

### *"HOURLYRESULTS" SHEET*

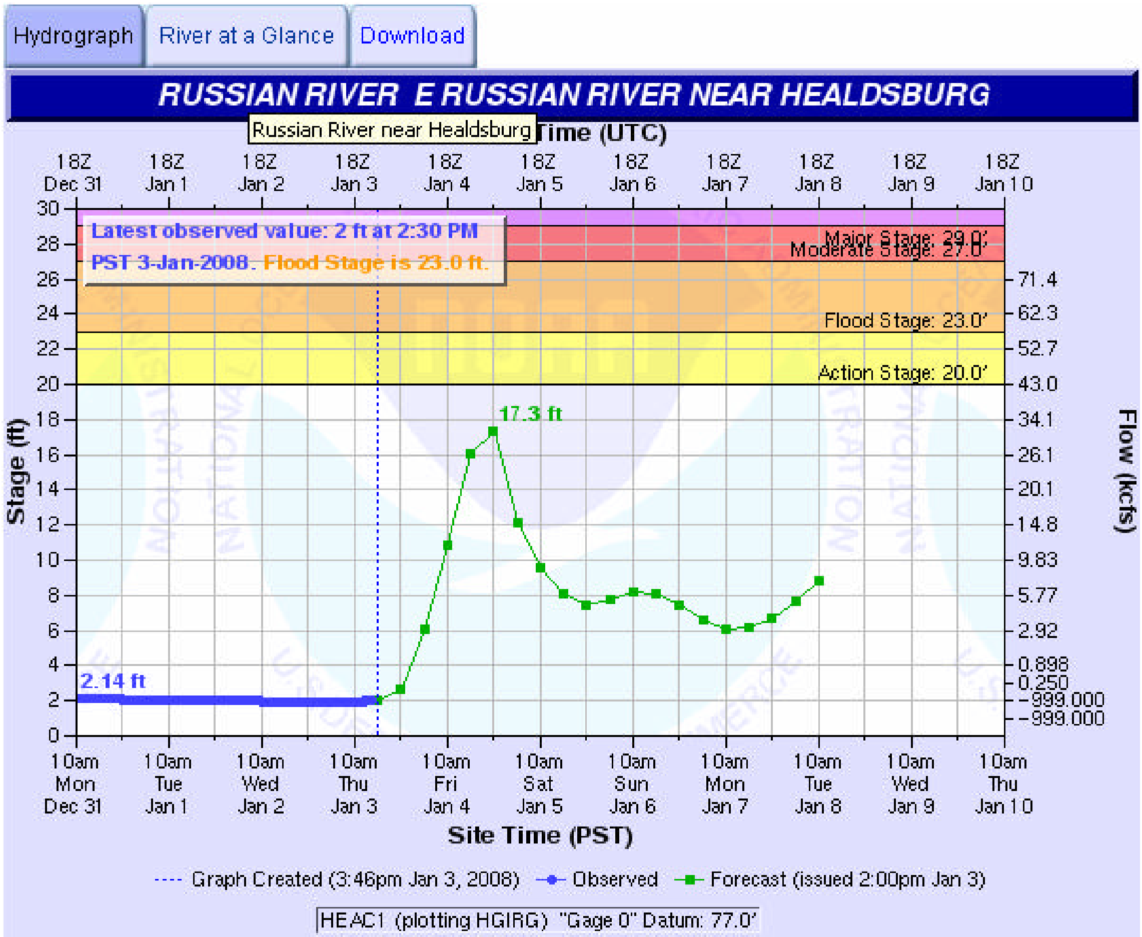
The macro populates the "Start" worksheet and stores the results from the model into memory for each time step (hour). The stored results include the maximum allowable flow (cfs and mgd), limiting criteria, and discharge criteria. Once all of the time steps have been run, the model prints the results on the "HourlyResults" worksheet, which contains the pre-defined charts for flow, temperature, dissolved oxygen, turbidity, and pH. The model also computes and reports the most limiting flow and criteria that occurred during the day of interest.

### *"RESULTS" SHEET*

The "Results" worksheet contains the results from the water balance model and spreadsheet model. The binding criteria for each day are specified, along with the volume of water that must be stored.

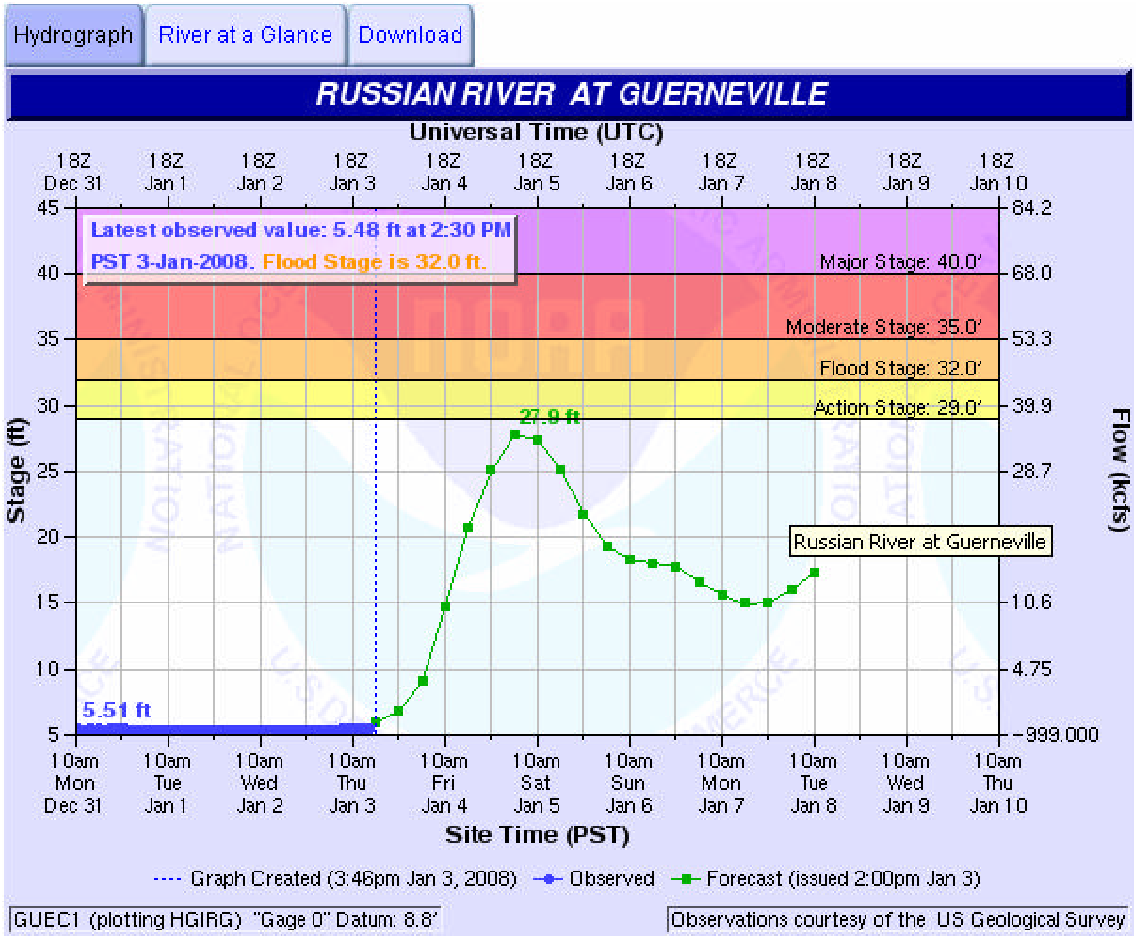
## *ADVANCED HYDROLOGIC PREDICTION*

Advanced hydrologic prediction services are available real-time on line from the national weather service. Two sites in the Russian River are included: Healdsburg and Guerneville. Existing flow data is shown and the predicted hydrograph for flow and stage are provided. These data can be augmented with predictions from the Napa River which illustrates a more rapidly ascending hydrograph due the flashiness of that basin. Through time, a relationship between The Laguna and or Santa Rosa Creek could possibly be developed to provide more insight to the operator. However, absolute magnitude is probably not as critical as timing of peak flows and return to a more stable flow regime.




(http://ahps2.wrh.noaa.gov/ahps2/hydrograph.php?wfo=mtr&gage=heac1&view=1,1,1,1,1,1,1,1)

**Figure 14. National Weather Service Advanced Hydrologic Prediction for the Russian River at Healdsburg (http://ahps2.wrh.noaa.gov/ahps2/index.php?wfo=mtr)**




(http://ahps2.wrh.noaa.gov/ahps2/hydrograph.php?wfo=mtr&gage=guec1&view=1,1,1,1,1,1,1,1)

**Figure 15. National Weather Service Advanced Hydrologic Prediction for the Russian River at Guerneville (http://ahps2.wrh.noaa.gov/ahps2/index.php?wfo=mtr)**