June 16, 2015

VIA COURIER

Ms. Katherine Mrowka
Enforcement Program, Manager
State Water Resources Control Board
1001 I Street, 14th Floor
Sacramento, California, 95814

Re: State Water Contractors' complaint against unlawful diversion of State Water Project stored water supplies.

Dear Ms. Mrowka:

This is a complaint against the unlawful diversion of stored State Water Project ("SWP") water. The State Water Contractors,[1] on behalf of itself and its member agencies, (herein "SWC") bring this complaint against diverters in the Delta located south of the San Joaquin River unlawfully diverting stored water from numerous points of diversion in excess of their water rights (herein "South-of-San Joaquin Diverters").[2] The South-of-San Joaquin Diverters are diverting water that they have no right to divert: SWP stored water supplies. This complaint does not challenge South-of-San Joaquin Diverters underlying water rights, rather this complaint assumes senior water rights can be substantiated, and the analyses contained herein informs when those with senior water rights are unlawfully diverting stored water supplies and should be curtailed.

Collectively, these South-of-San Joaquin Diverters are pumping approximately 100,000 to 300,000 acre-feet[3] more than they are entitled to in summer and fall of dry and critical years. The SWC are injured by the South-of-San Joaquin Diverters because approximately 100,000-300,000 acre-feet of their unlawful diversion causes the jointly operated State Water Project ("SWP") and the Central Valley Water Project ("CVP") to make additional stored water releases to satisfy Water Quality Control Plan ("WQCP") requirements. A 100,000 to 300,000 acre-feet unlawful diversion is significant. To put in context, 200,000 acre-feet equals the total amount of water that the SWC received in 2014. A 100,000 to 300,000 acre-feet increase in upstream storage would also significantly increase the ability of the SWP-CVP to maximize operational

---

[1] The SWC are a non-profit mutual benefit corporation representing 27 public water agencies that contract with the State of California through the Department of Water Resources ("DWR") for water from the SWP. The SWC was formed in 1982 to represent the interests of public water suppliers that hold contracts with the State of California for the delivery of water from the SWP. Pursuant to its powers and authorities, the SWC represents the interests of its Member Agencies in proceedings that affect the water supplies made available from the SWP. (List of Member Agencies, Attachment 1.) Collectively, the SWC Member Agencies serve water to more than 25 million persons, roughly two thirds of California's population, over a geographic area that extends from Butte County in the Sacramento Valley, through the San Francisco Bay Area and San Joaquin Valley to the California Central Coast and Southern California. The SWC Member Agencies also serve water to over 750,000 acres of irrigated farmland. The SWC is not required to file statements of diversion and use. (23 CCR § 820(d)).

[2] See map identifying location of South-of-San Joaquin Diverters, Attachment 2.

[3] This range reflects the two different approaches to calculating unlawful diversions. Once an approach is adopted, the predicted range of the potential impact will narrow.

flexibility in managing the system in dry and critical years. If this stored water were not being unlawfully diverted, it would be available to satisfy legally established project purposes.

The SWC are requesting that the State Water Resources Control Board ("Water Board") issue an order that requires the South-of-San Joaquin Diverters to cease and desist their excess diversions, as well as set forth standards under which the South-of-San Joaquin Diverters would be subject to an enforcement order. This request is further explained in subsequent sections of this complaint.

In this complaint, the SWC are presenting a new approach by providing information to estimate the timing and magnitude of the unlawful diversions, taking into account inflows and outflows, as well as antecedent conditions in the Delta. This approach is a way to move beyond historic arguments and present an analytical means to achieve resolution. Through modeling, the SWC have tested old assumptions and developed new modeling approaches to analyze in-Delta diversions. This complaint describes two methods for estimating the magnitude of unlawful diversions. The first method is an inflow criterion that is similar to what the Water Board has developed and is an method the SWC have previously presented to the Water Board. The second method is a salinity criterion that models water quality (salinity) without the SWP-CVP, which accounts for antecedent conditions, or the time history of flow, which is related to tidal conditions. The salinity criterion accounts for the relatively fresh conditions that remain in the Delta for a period of time after inflows diminish.

I. The Water Board Must Uphold the Water Right Priority System.

The Water Board should take immediate action to prevent the unlawful diversion of water pursuant to Water Code § 1831, and the SWC request that the Water Board use its authority to prevent unlawful diversions, waste, and unreasonable use of water.[4] The SWC have the right to file this complaint pursuant to Cal. Code of Regs. § 820, *et seq*.

The SWC are seeking immediate enforcement against all South-of-San Joaquin Diverters with post-1914 appropriative, pre-1914 appropriative and riparian water rights in 2015, as well as a standing order that describes conditions under which future enforcement is appropriate. The SWC seek a standing order that states:

- Delta diverters located south of the San Joaquin River with pre-1914 appropriative water rights, post-1914 appropriative water rights and/or riparian water rights have no right to divert SWP-CVP stored water supplies pursuant to their water rights.

- Delta diverters located south of the San Joaquin River with post-1914 appropriative water rights, pre-1914 appropriative water rights and/or riparian water rights shall be curtailed according to water right priority once in-Delta use exceeds Delta inflows in the without SWP-CVP scenario.

---

[4] Cal. Water Code §§ 100, 275; California Constitution, Article X, section 2; *California Farm Bureau Federation v. SWRCB* (2011) 51 Cal. 4th 421, 429 [while the Water Board "…has no permitting or licensing authority over riparian or pueblo rights, or over appropriative rights acquired before 1914. The SWRCB does have authority to prevent illegal diversions and to prevent waste or unreasonable use of water, regardless of the basis under which the right is held]; *United States v. SWRCB*, 182 Cal.App3d. 82 (1986); *Young v. SWRCB*, 219 Cal.App.4th 397, 404 (2013).

- Delta diverters located south of the San Joaquin River with post-1914 appropriative water rights, pre-1914 appropriative water rights and/or riparian water rights do not have the right to divert when Delta salinity (measured as specific conductance) in the without the SWP-CVP scenario is at least 2.0 mS/cm[5] or greater.

The findings to support this standing order should include the following:

- The WQCP, the area of origin statutes, and the Delta Protection Act did not expand the rights of diverters with pre-1914 appropriative water rights, post-1914 appropriative water rights and/or riparian water rights to include the right to divert SWP stored water supplies.[6]

- Delta diverters with pre-1914 appropriative water rights, post-1914 appropriative water rights and/or riparian rights cannot divert foreign water, which includes stored reservoir releases that have not been abandoned.

- Without SWP-CVP operations, water quality in the Delta south of the San Joaquin River would degrade significantly and for prolonged periods of time with limited potential for salinity flushing and drainage, which impact the ability to reasonably and beneficially use water with elevated salinity for agricultural purposes.

- The proper modeling baseline for determining when water is available for diverters with pre-1914 appropriative water rights, post-1914 appropriative water rights, and/or riparian water rights is the current channel configuration without the operation of the SWP-CVP as Delta vested water right holders are entitled to no more water supply than without project flows and the resulting salinity conditions.[7]

- Since Delta diverters south of the San Joaquin River do not actually experience without SWP-CVP flow and salinity conditions, it is appropriate to model without project conditions to capture the points in time when Delta diverters would not otherwise be able to put available supplies to reasonable and beneficial use, which is the maximum extent of their alleged water rights.

- Physical conditions in the Delta south of the San Joaquin River impact the ability to reasonably and beneficially use water with elevated salinity for agricultural purposes.

- Due to physical conditions in the Delta south of the San Joaquin River both currently and if the SWP-CVP were not operated, diverters with pre-1914 appropriative water rights, post-1914 appropriative water rights and/or riparian water rights cannot put

---

[5] The justification for a 2.0 mS/cm standard is provided in section II(b), below.

[6] *See e.g*., Cal. Water Code §11462; *El Dorado Irrigation District v. State Water Resources Control Board*, 142 Cal. App.4th 937, 967, 976 (2016) *Phelps v. SWRCB*, 157 Cal.App.4th 89, 110 (2007). The co-mingling rules apply only if the South-of-San Joaquin Diverters could have otherwise diverted absent the existence of the SWP-CVP.

[7] *See e.g., In the Matter of Administrative Civil Liability Complaints for Violations of Licenses 13444 and 13274 of Lloyd L. Phelps, Jr.; License 1319 of Joey P. Ratto, Jr.; License 13315 of Ronald D. Conn and Ron Silva et al.* State Water Resources Control Board. Order WRO 2004-004, p. 12 (2004 Cal. ENV.LEXIS 104); *In the Matter of Permit 12720 (Application 5625) and Other Permits of the U.S. Bureau of Reclamation for the Federal Central Valley Project and of California Department of Water Resources for the State Water Project. State Water Resources Control Board.* Order WR 78-17 at 23 (1978 Cal. ENV LEXIS 35.)

water with salinity greater than 2.0 mS/cm to reasonable and beneficial agricultural use.

- Based on evidence presented to the Water Board, 2.0 mS/cm is a conservative and reasonable estimate of when a salt tolerant crop grown in the Delta would experience decreased yield.

The standing order is necessary to protect the SWP-CVP water supplies from unlawful diversions, thereby making those supplies unavailable to satisfy multiple legally established project purposes.

II. Evidence of Unlawful Diversions of SWP Stored Water Supplies Supports Swift Enforcement by the Water Board.

In this complaint, the SWC present two approaches to calculating the magnitude of the unlawful diversions: an inflow criterion and a salinity criterion. Regardless of which method is used for the calculation (or to the extent both are used), the magnitude of the South-of-San Joaquin Diverters' unlawful diversion is 100,000 to 300,000 acre-feet this year, with similar losses of stored water supplies in future years during summer and fall, particularly in drier years.

a. Unlawful diversions are occurring when in-Delta use exceeds inflows; SWP stored water supplies require protection.

The inflow criterion takes available inflow coming into the Delta from the Sacramento and San Joaquin River watersheds and subtracts in-Delta water use. When in-Delta use exceeds available inflow curtailments are triggered.

As Figure A illustrates, when outflow (green) crosses zero (gray dash), the curtailment is triggered. The magnitude of the curtailment is the extent that in-Delta use (blue) exceeds inflow (red). The curtailment would end when outflows (green) increase and are once again above zero (gray dash) or when inflow (red) exceeds in-Delta use (blue). Figure B further illustrates the relative magnitude and timing of curtailments using this approach. Curtailments would begin with post-1914 appropriators and pre-1914 appropriators according to water right priority; and after all of the senior appropriators are curtailed, the riparian water users would be curtailed correlatively, based on percent reductions in water use.

The SWC's inflow analysis shows that the curtailment pattern would be centered in the summer (June-August). Using this approach, curtailments would occur in a large number of years, including some normal water years. Using this approach, the in-Delta water use exceeds available inflows from the combined Sacramento and San Joaquin River watersheds 20% of the time in June, 50% of the time in July, and 40% of the time in August. (See Table V.2, p. 11, Attachment 3.)[8] These percentages reflect the percentage of years when curtailments would be triggered using

---

[8] The assumption that water from both the Sacramento and San Joaquin River watersheds could be used in an inflow analysis may overestimate the quantity of water available to the area of the Delta south of the San Joaquin River because this area (or portions of this area) do not appear to be riparian to the Sacramento River, and it is therefore also unlikely that the South-of-San Joaquin Diverters could be appropriating water from the Sacramento River under a senior water right. The area south of the San Joaquin River does not appear to be riparian to the Sacramento River for the following reasons: 1.) the properties are located upstream of the confluence of the Sacramento and San Joaquin Rivers, 2.) none of the properties have frontage on the Sacramento River, and 3.) it would not appear that rain water draining from these areas would drain into the Sacramento River which suggests they are

this approach. The diverters Delta-wide are pumping approximately 600,000 acre-feet in excess of available inflows in extreme dry years, with approximately 300,000 acre-feet of this unlawful use attributed to the South-of-San Joaquin Diverters. (See Tables V.3-V.4, p. 12, Attachment 3.)

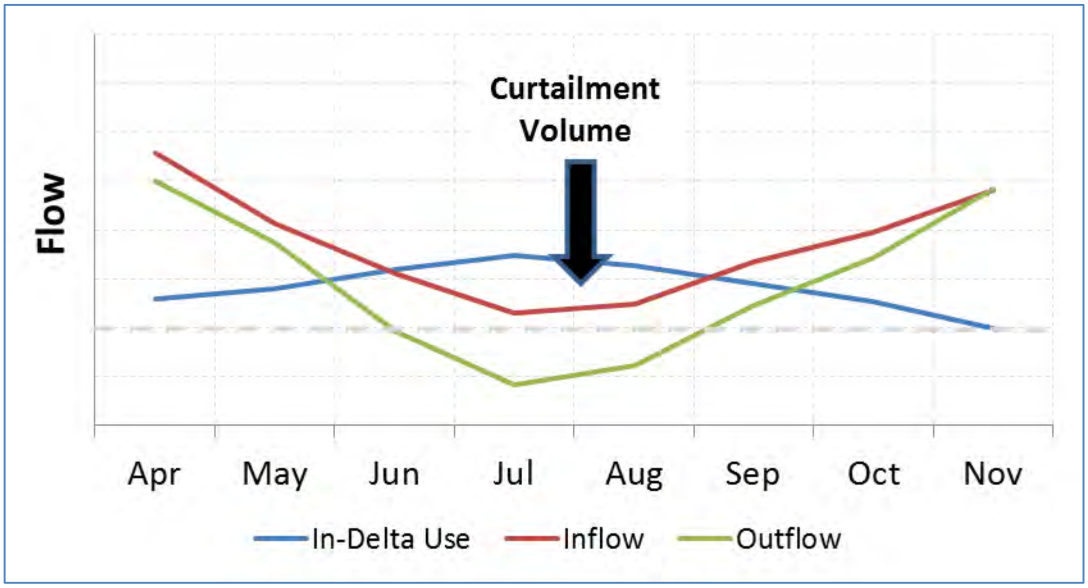


Figure A. Inflow Criterion. Conceptual inflow trigger illustration.

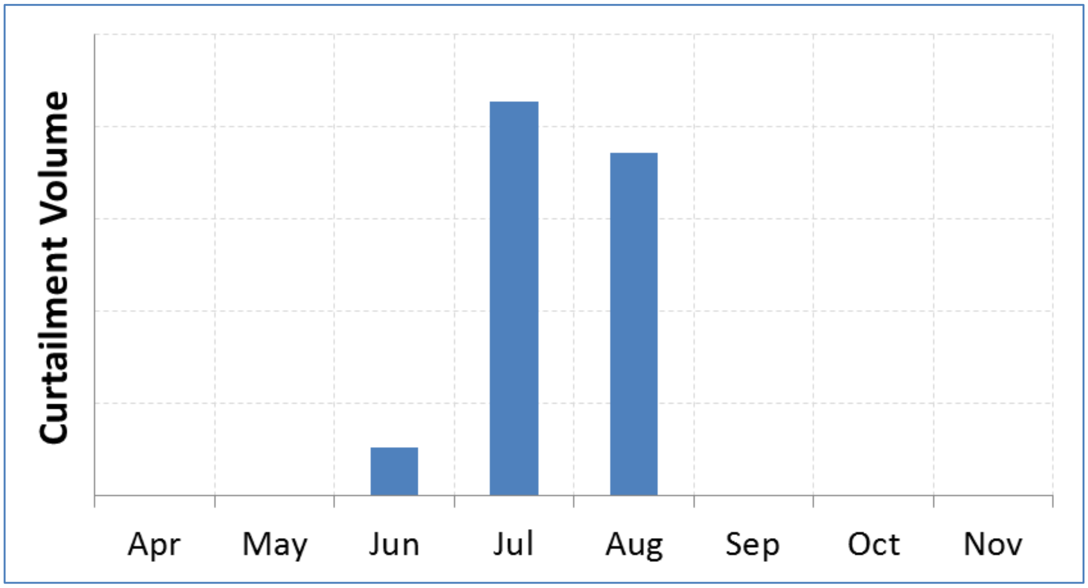


Figure B. Conceptual magnitude and timing of unlawful diversion of stored water supplies using inflow criterion.

The inflow approach does not account for antecedent conditions, or the time history of flow, which is related to tidal conditions in the Delta. The SWC salinity analysis is a means by which the Water Board could trigger curtailments while accounting for both inflow and antecedent conditions.

---

not in the Sacramento River watershed. The percentage of the time that in-Delta use south of the San Joaquin River exceeds available inflow from only the San Joaquin River watershed would be even greater than the percentages identified above.

b. Unlawful diversions are occurring when salinity is too high to support reasonable and beneficial use; SWP stored water supplies require protection.

The salinity criterion considers the water available to the South-of-San Joaquin Diverters at their points of diversion absent the existence of the SWP-CVP. This approach provides information about when the South-of-San Joaquin Diverters would be able to beneficially use Delta water if the SWP-CVP neither operated facilities in the Delta nor stored water upstream of the Delta. This approach shows that if the SWP-CVP did not exist, the South-of-San Joaquin Diverters would frequently be unable to divert in dry and critical years because the water quality would be too poor for reasonable and beneficial use. When water quality without the SWP-CVP is too poor for reasonable and beneficial use at all points of diversion within a region, the affected South-of-San Joaquin Diverters have no water right that can be exercised, and thus would be completely curtailed.[9] Using this approach, all South-of-San Joaquin Diverters would not be curtailed at the same time. As salinity increases generally start downstream, the downstream areas would be curtailed first. See Figure C.

As Figure C illustrates, in the without SWP-CVP scenario, salinity moves into the Delta starting in the north and west, ultimately moving further south and east into the Delta as outflow decreases. Based on a salinity trigger of 2.0 mS/cm, Figure C illustrates the curtailment progression.

Salinity and antecedent outflow (which accounts for the time history of flows from prior months) have an inverse relationship, because salinity increases as antecedent outflow decreases. See Figure D. In Figure D, the increasing size of the region subject to curtailment tracks the trajectory of salinity (orange). A salinity trigger would result in a curtailment pattern that occurs over a greater period of time within a year but it would not be triggered in as many years as the inflow trigger. See Figure E.

Figure C. Conceptual illustration of salinity criterion

---

[9] Cal. Const., Art. X, Sec. 2; *See e.g., Peabody v. City of Vallejo*, 2 Cal.2d. 351, 383 (1935) ["The rule of reasonable use…applies to all water rights enjoyed or asserted in this state, whether the same be grounded on the riparian right or the right, analogous to the riparian right, of the overlying land owner, or the percolating water right, or the appropriative right."]

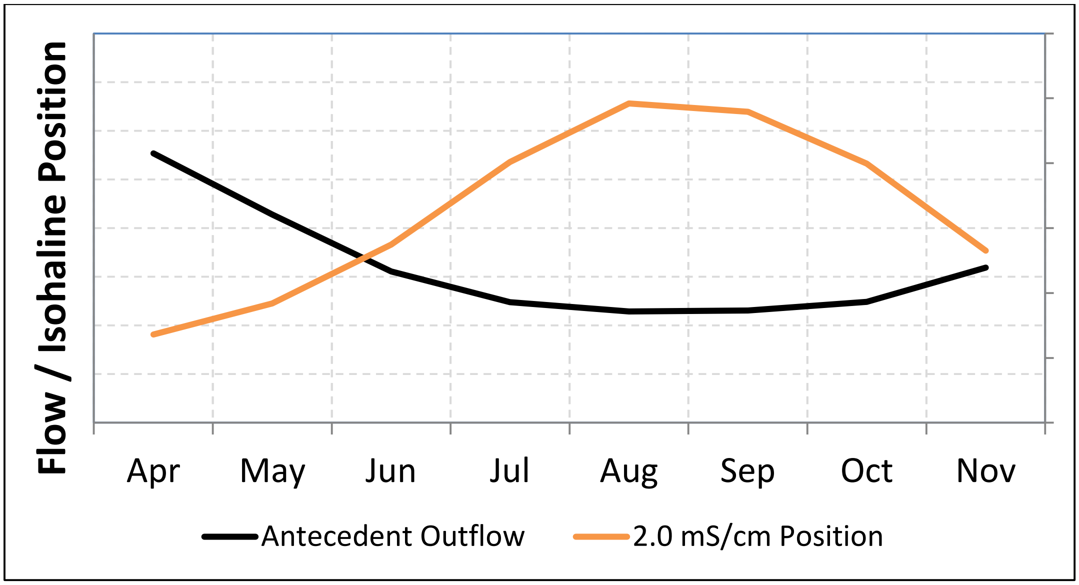


Figure D. Conceptual relationship between antecedent outflow and salinity.

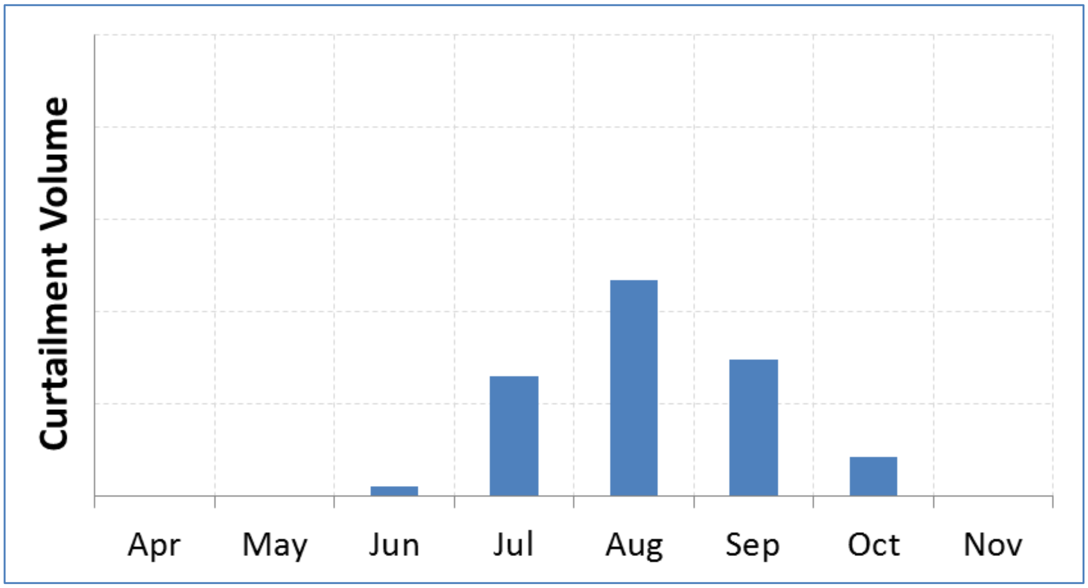


Figure E. Conceptual magnitude and timing of unlawful diversion of stored water supplies using the salinity criterion.

The salinity criterion would likely be triggered only in dry and critical years.

Salinity in Delta channels south of the San Joaquin River is often 2.0 mS/cm or greater during the irrigation season of dry and critical years under without project conditions, which is more than twice the 0.7 mS/cm April-August southern Delta agricultural salinity standard. (See, Attachment 5, Figures 5-52, pp.7-56.) For example, salinity south of the San Joaquin River ranged from 2.0 mS/cm to over 10 mS/cm in August 2014 (a critically dry year) under without project conditions. See Figure F below. This year (2015) is comparable to 2014 under without project conditions, with salinity between 2.0 mS/cm to over 10 mS/cm throughout the area south of the San Joaquin River. (See, Attachment 5, Figures 50-52, pp. 54-56.) In both years, salinity remains high throughout the fall into November and December, illustrating how long seawater intrusion can linger in the Delta during critical years. See Figure G below. In years like 2014, the South-of-San Joaquin Diverters should be curtailed in the summer and throughout the fall.

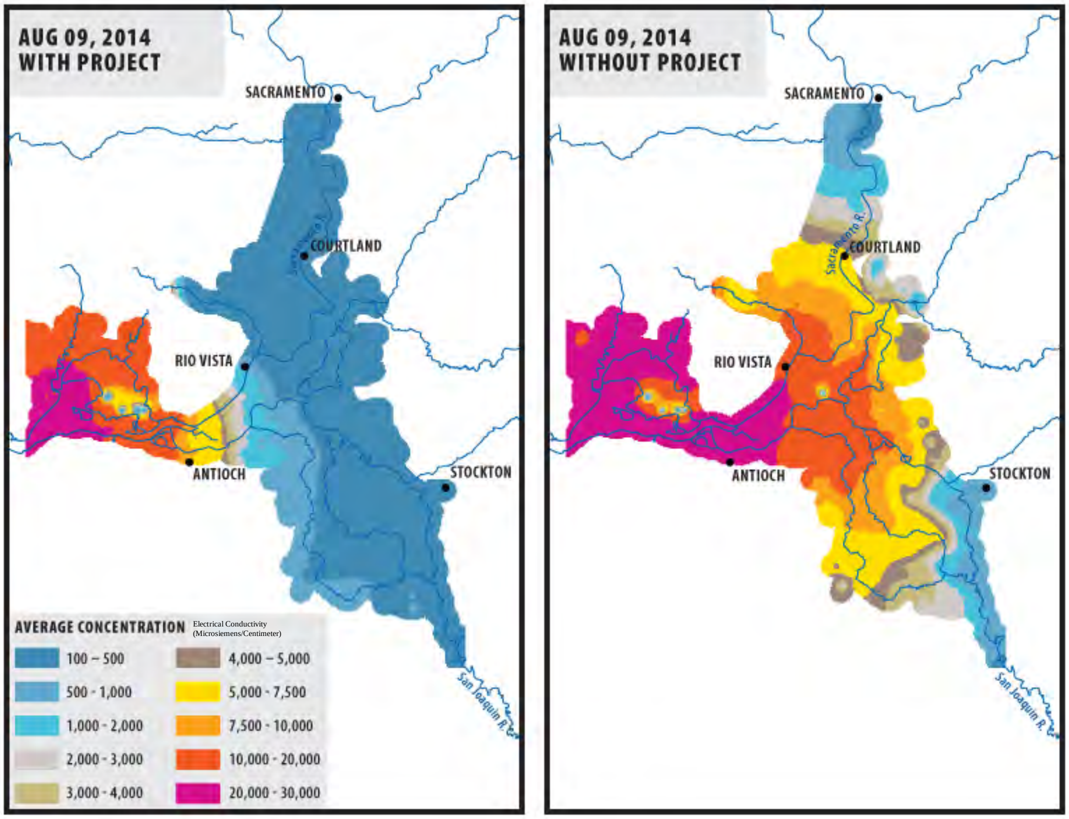


Figure F. Delta salinity comparison of with and without project scenario, August 2014. See Attachment 5, p. 42, supporting documentation for salinity comparison.

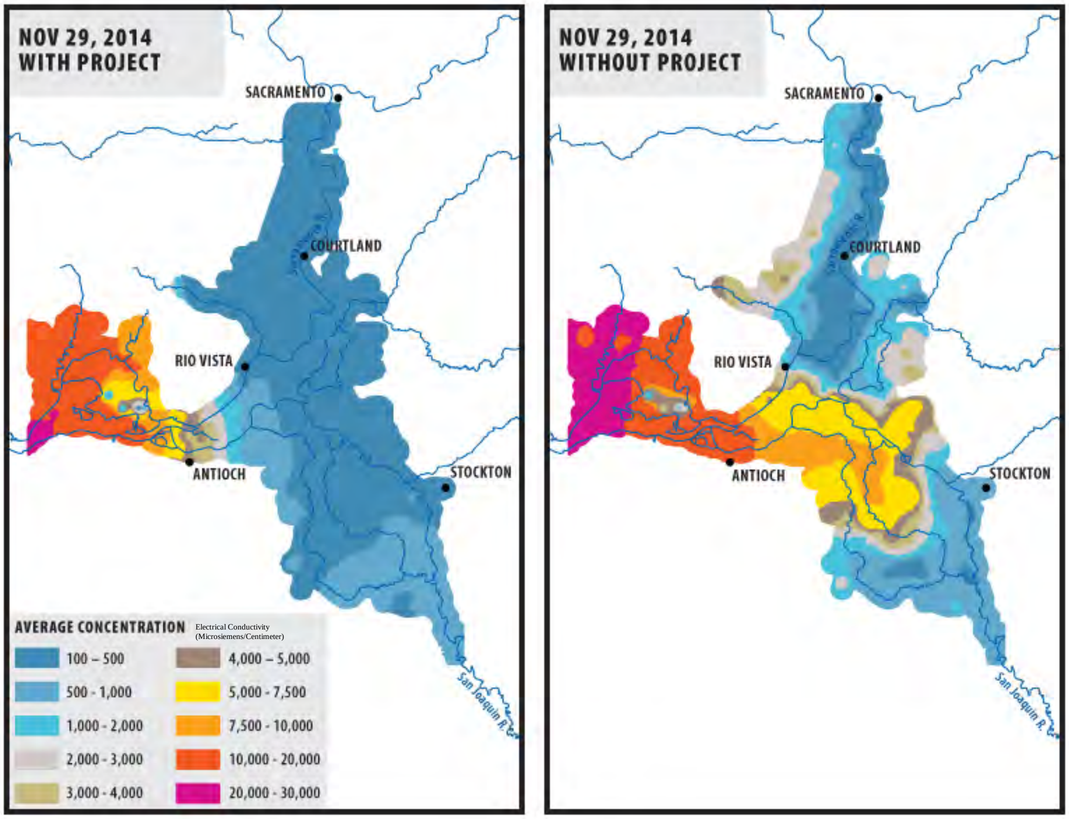


Figure G. Delta salinity comparison of with and without project scenario, November 2014. See Attachment 5, p. 45, supporting documentation for salinity comparison.

It is reasonable to use 2.0 mS/cm as the salinity criterion, which is more than double the current 0.7 mS/cm irrigation season agricultural salinity standard for determining reasonable and beneficial use based on water quality. The Hoffman (2010)[10] report used a modeling approach in an effort to account for the South Delta Water Agency's ("SDWA") ongoing criticisms about the need to consider leaching fractions, and the inability to apply laboratory experiments to determine salinity tolerance. Hoffman (2010)[11] generally concluded that an agricultural salinity standard around 1.0 mS/cm (0.7 - 1.4 mS/cm) was sufficiently protective. Hoffman (2010) did not consider the issue being posed in this complaint, that being what is the maximum salinity tolerance of the most salt tolerant crops being grown in the Delta? Even so, the South-of-San Joaquin Diverters (through the SDWA) have argued before the Water Board on multiple occasions that the current 0.7 mS/cm (April-August) agricultural standard is insufficiently protective, and in fact even at 0.7 mS/cm the South-of-San Joaquin Diverters have previously testified that they experience injury to their farming viability, arguing against raising the WQCP standard to 1.0 mS/cm.[12] If the SDWA is correct and the South-of-San Joaquin Diverters would be experiencing

---

[10] Hoffman, G., (2010) *Salt Tolerance of Crops in the Southern Sacramento-San Joaquin Delta*, Final Report, for the California Environmental Protection Agency, State Water Resources Control Board.

[11] *Id.* at p. 98.

[12] *See e.g.*, South Delta Water Agency, Power Point titled "Water Quality Objectives for Agricultural Beneficial Uses in the Southern Delta," presented during public hearing on the adequacy of the substitute environmental documents (Phase I), March 20-21, 2013 ["Hoffman Report are not supported [by] any, much less substantial evidence…Hoffman didn't know: The amount of salts in the soil; The amount of salt applied; The amount of water or salt that passed through the root zone; The amount of ground water/salts in the drainage; The amount of salt remaining in the root zone; All of which prevent him [Hoffman] from calculating the leaching fraction," and Hoffman did not account for the salty groundwater as, "Most of the Southern Delta ag land is between

crop losses at 0.7mS/cm or 1.0 mS/cm, then doubling that salinity level would be expected to cause significant impairment and loss of agricultural viability to the extent water quality of 2.0 mS/cm could not be put to reasonable and beneficial agricultural use.

When salinity would have been too high to support the water rights absent the SWP-CVP operations, the South-of-San Joaquin Diverters have no right to divert and should be curtailed. Using the conservative 2.0 mS/cm salinity trigger, the South-of-San Joaquin Diverters are pumping approximately 100,000 – 300,000 acre-feet in excess of their alleged water rights.

IV. Conclusion

The SWC are seeking immediate enforcement this year, and a standing order for future dry and critical water-years. The Water Board should take immediate action to protect 100,000 to 300,000 acre-feet of stored water supplies.

Sincerely,

Stefanie Morris

Stefanie D. Morris
General Counsel

Attachments

-5 to +10 feet compared to sea level. The shallow ground water in the area is directly linked to the channel water and thus rises and falls twice daily with the tides. That shallow ground water contains the accumulation of 50+ years of CVP salts. Thus, when the tides rise and fall, the salty ground water rises and falls entering or approaching the root zone. This means any salts which are leached do not go anywhere!" [*emph. in original*).]

Attachment 1

SWC MEMBERS

Alameda County Flood Control & Water Conservation District, Zone7
100 North Canyons Parkway
Livermore, CA 94551

Alameda County Water District
P.O. Box 5110
Fremont, CA 94537

Antelope Valley-East Kern Water Agency
6500 West Avenue N
Palmdale, CA 93551-2855

Casitas Municipal Water District
1055 Ventura Avenue
Oakview, CA 93022-9622

Castaic Lake Water Agency
27234 Bouquet Canyon Road
Santa Clarita, CA 91350

Central Coast Water Authority
255 Industrial Way
Buellton, CA 93427-9565

City Of Yuba City
1201 Civic Center Blvd
Yuba City, CA 95993

Coachella Valley Water District
75-515 East Hovley Lane
Palm Desert, CA 92211

County Of Kings
1400 West Lacey Blvd
Hanford, CA 93230

Crestline-Lake Arrowhead Water Agency
P.O. Box 3880
Crestline, CA 92325

Desert Water Agency
P.O. Box 1710
Palm Springs, CA 92263-1710

Dudley Ridge Water District
286 W. Cromwell Ave
Fresno, CA 93711-6162

Empire West Side Irrigation District
P.O. Box 66
Stratford, CA 93266

Kern County Water Agency
P.O. Box 58
Bakersfield, CA 93308

Littlerock Creek Irrigation District
35141 87th St E
Littlerock, CA 93543

Metropolitan Water District of Southern California
P.O. Box 54153 Terminal Annex
Los Angeles, CA 90054

Mojave Water Agency
13846 Conference Center Drive
Apple Valley, CA 92307

Napa County Flood Control and Water Conservation District
804 First Street
Napa, CA 94559

Oak Flat Water District
17840 Ward Avenue
Patterson, CA 95363

Palmdale Water District
2029 East Avenue Q
Palmdale, CA 93550

San Bernardino Valley Municipal Water District
380 East Vanderbilt Way
San Bernardino, CA 92408

San Gabriel Valley Municipal Water District
P.O. Box 1299
Azusa, CA 91702

San Gorgonio Pass Water Agency
1210 Beaumont Avenue
Beaumont, CA 92223

San Luis Obispo County Flood Control and
Water Conservation District
County Government Center, Room 207
San Luis Obispo, CA 93408

Santa Clara Valley Water District
5750 Almaden Expressway
San Jose, CA   95118

Solano County Water Agency
810 Vaca Valley Parkway
Vacaville, CA 95688

Tulare Lake Basin Water Storage District
1001 Chase Avenue
Corcoran, CA 93212

Attachment 2

The South of San Joaquin River Diverters have points of diversions at numerous locations south of the San Joaquin River within the legal Delta (marked in yellow).

Attachment 3

SOUTH DELTA WATER USE ANALYSIS

A Technical Appendix Supporting a Water Rights Complaint against Delta Diverters South of the San Joaquin River For Unauthorized Diversions of Stored Project Water

Paul H. Hutton, Ph.D., P.E.

Metropolitan Water District of Southern California

May 2015

Table of Contents

I. Executive Summary

The State Water Contractors have undertaken several technical studies to evaluate the extent that unauthorized diversions of stored water from the State Water Project (SWP) and Central Valley Project (CVP) are occurring in the Delta south of the San Joaquin River. This document provides a brief summary of these technical studies. These technical studies assume that riparian water rights and pre-1914 appropriative water rights are senior to those of the SWP and CVP. These technical studies also assume that those currently diverting pursuant to a claimed senior water right would be able to prove the existence of such a right. The senior water rights are associated with water that would have been available in the system absent the operation of SWP-CVP upstream storage and in-Delta facilities, a hypothetical "without project" condition.

Two approaches are presented for estimating the availability of water for in-Delta agricultural users; these approaches are applied to the study area south of the San Joaquin River under the without project condition. The first approach, an inflow criterion, assumes at one bound that when Delta inflow approaches zero, no water is available in the study area and curtailment of all water use is warranted. At the other bound, the criterion assumes that if Delta outflow is positive, i.e. Delta inflow exceeds full in-Delta water use, water is available for all in-Delta use and no curtailment is warranted. Between these bounds, the inflow criterion assumes that study area water use is curtailed such that it does not exceed Delta inflow. The second approach, a salinity criterion, assumes that water is available for use within the study area provided that water is of adequate quality for beneficial use. This approach requires the use of Delta salinity models and specification of a salinity "trigger" to estimate water availability. Given that extremely low outflow conditions characteristic of the "without project" hydrology are outside the calibration range of available Delta salinity models, data collected in the 1920s and 1930s before construction of Shasta Dam were examined to assess the validity of the proposed modeling approach. Two key conclusions were drawn from this data examination: (1) the study area was subject to severe seawater intrusion before construction and operation of the SWP-CVP and (2) the use of DSM2 and DSM2-calibrated flow-salinity models allow for a reasonable and conservative method of evaluating water supply availability in the study area as part of the salinity criterion.

The inflow criterion analysis suggests that unauthorized diversions are taking place in the study area, these diversions are centered in the April through August period, and excess diversions are in the range of 300,000 acre-feet in dry and critical water years. The inflow criterion suggests that excess diversions take place in most years, but in smaller volumes under wetter hydrologic conditions. The salinity criterion analysis also suggests that unauthorized diversions are taking place in the study area. However, these diversions are later in the season (typically June through November) with lower volumes in the range of 100,000 to 200,000 acre-feet in dry and critical water years. The salinity criterion suggests that excess diversions are of little consequence under wetter hydrologic conditions.

II. List of Tables

III. List of Figures

IV. Introduction

The State Water Contractors have undertaken several technical studies to evaluate the extent that unauthorized diversions of stored water from the State Water Project (SWP) and Central Valley Project (CVP) are occurring in the Delta south of the San Joaquin River. This document provides a brief summary of these technical studies. Detailed findings are documented in individual project reports; these reports are listed in the References section of this document.

These technical studies assume that riparian water rights and pre-1914 appropriative water rights are senior to those of the SWP and CVP. These technical studies also assume that those currently diverting pursuant to a claimed senior water right would be able to prove the existence of such a right. The senior water rights are associated with water that would have been available in the system absent the operation of the SWP-CVP facilities in the Delta (i.e. no pumping facilities and no Delta cross channel with gates) and absent stored water upstream of the Delta (referred to herein as the "without project conditions"). Therefore, many of these technical studies define and utilize a hypothetical hydrology to represent flows and salinity that would exist without the SWP-CVP.

Section V summarizes a simple inflow analysis that was conducted to estimate the availability of surface water in the Delta for agricultural use. This analysis, which was conducted over the entire Delta as well as the area south of the San Joaquin River (herein referred to as the "study area", identifies without project conditions when (1) monthly Delta inflow is positive and (2) monthly Delta outflow is positive. This classification is used to assess the availability of water for assumed senior water rights under a wide range of hydrologic conditions and is used to estimate the extent that water use in the study area has exceeded available inflow historically using the historical 91-year hydrologic record spanning water years 1922-2012 (October 1921 through September 2012). This analysis is referred to herein as the "inflow criterion".

Section VI, building on the findings of Section V, summarizes an evaluation of surface water availability in the study area under without project conditions that is of adequate quality to meet agricultural beneficial uses. This analysis utilizes the DSM2 model to simulate water quality under without project conditions using an 82-year hydrologic record (water years 1922-2003) that represents current land use in the Sacramento and San Joaquin River basins. Utilizing these modeling results, a conceptual approach to trigger water use curtailments based on available water quality (referred to herein as the "salinity criterion") is presented. This section also summarizes an analysis of historical water quality measurements, prior to construction of the SWP-CVP, to provide a quasi-validation of the modeling results.

Additional technical studies that build on the analyses contained herein were undertaken by the State Water Contractors and are presented in separate documents. One such study utilizes the DSM2 model to extend the without project conditions salinity analysis to water years 2012-15. Another technical study analyzes Delta island water use, including: (1) possible water management scenarios that result from water curtailment on Delta islands; (2) consequences of possible curtailment of Delta diversions in the study area, (3) the response of key water budget components and Delta island water budgets to curtailment and alternative land and water management strategies, (4) uncertainty in the estimation of water budget components, and (5) the response of salinity on Delta islands to water curtailment and different land and water management practices. A third study utilizes the C2VSim integrated groundwater surface water model to evaluate the viability of current land use practices in the Sacramento River basin absent the SWP-CVP.

V. Analysis of Surface Water Availability (Inflow Criterion)

The availability of surface water for agricultural use in the study area was evaluated through a simple inflow approach or criterion. This approach estimates water availability on an average monthly basis by removing the effects of SWP-CVP reservoirs and Delta facilities (i.e. without project conditions) from the historical record of Delta hydrology. This hypothetical hydrology is then used to evaluate water availability by identifying when (1) monthly Delta inflow is positive and (2) monthly Delta outflow is positive. It is assumed that when monthly Delta inflow approaches zero, no water is available for in-Delta agricultural use and curtailment of all water use in the study area is warranted. Furthermore, it is assumed that if monthly Delta outflow is positive, i.e. Delta inflow exceeds full in-Delta water use, water is available for all in-Delta use and no curtailment is warranted. This latter assumption ignores circumstances when Delta outflow is positive but sufficiently small such that seawater intrusion impairs the beneficial use of water in the study area, thereby limiting water availability for diversion. These circumstances are evaluated and discussed in Section VI. The methods and results for the surface water availability analysis are described below.

A. Methods

The methods used to evaluate the availability of surface water for agricultural use in the study area are described below. The data used for the analysis are identified and the calculation approach is defined.

1. Data

Monthly average data spanning the period October 1921 through September 2012 were assembled into an electronic spreadsheet file from a variety of sources. Data and sources are summarized in Table V.1.

2. Delta Inflow and Outflow Calculations

Historical total Delta inflow, by definition, was calculated by summing the various Delta inflows as follows:

$$Historical\ Total\ Delta\ Inflow = Q_{freeport} + Q_{yolo} + Q_{east} + Q_{vernalis} \dots\dots\dots\dots\dots (V.1)$$

where $Q_{freeport}$ is Sacramento River inflow at Freeport; Q_{yolo} is Yolo Bypass inflow; Q_{east} is inflow from the Cosumnes, Mokelumne and Calaveras Rivers; and $Q_{vernalis}$ is San Joaquin River inflow at Vernalis.

Historical Sacramento River inflow at Freeport was adjusted to remove the effects of upstream SWP-CVP storage operations through the following calculation:

$$Q_{freeport\ w.o.\ project} = Q_{freeport} - Q_{trinity} + \sum Q_{sac\ storage} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. (V.2)$$

where $Q_{trinity}$ is import from the Trinity River watershed and $\Sigma\ Q_{sac\ storage}$ is the flow associated with removing storage operations at Shasta, Oroville and Folsom. Historical storage increases are added to the without project river flows; historical storage releases are subtracted from the without project river flows. This calculation results in a long-term balance between storage increases and storage releases and ignores small losses associated with evaporation from the reservoirs and local withdrawals. The adjusted Freeport inflow is constrained to always be ≥ 0.

Data Type	Data Source	Comments
Delta Inflow: October 1921 – September 1929	Joint Hydrology Study (DWR & USBR 1958)	---
Delta Inflow: October 1929 – September 2012	DAYFLOW Database (DWR 2012a)	---
CCWD Diversions	DAYFLOW Database (DWR 2012a)	---
Delta Net Channel Depletions: October 1921 – September 1929	Joint Hydrology Study (DWR & USBR 1958)	---
Delta Net Channel Depletions: October 1929 – September 2012	DAYFLOW Database (DWR 2012a)	---
Trinity Imports	USGS Website	---
Reservoir Storage	CDEC (DWR 2012b)	Shasta, Oroville, Folsom, New Melones
Millerton Lake Inflow: October 1921 – September 1994	Provided by Andy Draper (MWH) 1/27/15	CalSim II input data
Millerton Lake Inflow: October 1994 – September 2012	Provided by Andy Draper (MWH) 1/27/15	USACE Website
Millerton Lake Outflow	Provided by Andy Draper (MWH) 1/27/15	USGS Website
SJR Exchange Contractor Diversions & Return Flows: D607B; R619H; R614J	Provided by Sujoy Roy (Tetra Tech) 1/27/15	CalSim II input data

Table V.1 Data Summary for Surface Water Availability Analysis

Similarly, historical San Joaquin River inflow was adjusted to remove the effects of upstream CVP storage operations through the following calculation:

$$Q_{vernalis\ w.o.project} = Q_{vernalis} + Q_{inM} - Q_{outM} - Q_{dep} - Q_{exc} + \sum Q_{nm\ storage} \dots\dots\dots (V.3)$$

where Q_{inM} and Q_{outM} are Millerton Reservoir inflow and outflow, respectively; Q_{dep} is channel depletion to groundwater between Millerton Reservoir and Mendota Pool (assumed equal to zero in this analysis); Q_{exc} is water use by the San Joaquin River Exchange Contractors; and $\Sigma\ Q_{nm\ storage}$ is the flow associated with removing storage operations at New Melones. Without project Vernalis flow was set equal to historical Vernalis flow prior to October 1941, the date of initial Friant Dam operation. To account for periods when the full consumptive demand of the San Joaquin River Exchange Contractors was not available in the river, the following calculation was made:

$$Q_{exc} = MIN\left(D607B - R619H - R614J, Q_{inM} - Q_{dep}\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. (V.4)$$

where D607B is Exchange Contractor diversion and R619H and R614J are Exchange Contractor return flows as defined in CalSim II input data. The adjusted Vernalis inflow is constrained to always be ≥ 0.

Given the above calculations, without project total Delta inflow is calculated as follows:

$$Without\ Project\ Total\ Delta\ Inflow = Q_{freeport\ w.o.project} + Q_{yolo} + Q_{east} + Q_{vernalis\ w.o\ project} \dots\dots\dots (V.5)$$

and without project Delta outflow is calculated as follows:

$$Without\ Project\ Delta\ Outflow = Without\ Project\ Total\ Delta\ Inflow - Q_{ccwd} - Q_{ncd} \dots\dots\dots\dots\dots\dots (V.6)$$

where Q_{ccwd} is historical Contra Costa Water District diversion and Q_{ncd} is historical agricultural net channel depletion.

3. Estimating Full Water Use in Study Area

The following reconnaissance-level calculation was used to estimate full or unrestricted water use in the study area:

$$Full\ Water\ Use = Q_{ncd} * \frac{A_{south}}{A_{Delta}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (V.7)$$

where Q_{ncd} was previously defined as historical agricultural net channel depletion, A_{south} is the irrigated area in the study area and A_{Delta} is the irrigated area in the Delta. This analysis assumed A_{south} = 186,700 acres and A_{Delta} = 393,400 acres (Tetra Tech Inc. 2015a). This estimate could be refined through modeling analysis using the Delta Island Consumptive Use (DICU) model.

B. Results

Using the methods described above, Delta inflow and outflow under without project conditions were calculated for every month over the period October 1921 through September 2012. The availability of surface water for agricultural use in the study area was then evaluated by identifying when (1) monthly Delta inflow is positive and (2) monthly Delta outflow is positive. It is assumed that when monthly Delta inflow approaches zero, no water is available for in-Delta agricultural use and curtailment of all use in the study area is warranted[1]. Furthermore, it is assumed that if monthly Delta outflow is positive, i.e. Delta inflow exceeds full in-Delta water use, water is available for all use in the study area and no curtailment is warranted. This latter assumption ignores circumstances when Delta outflow is positive but sufficiently small such that seawater intrusion impairs water quality to the extent that the available supply could not be put to reasonable and beneficial use.

---

[1] As described previously under Methods, Freeport and Vernalis inflows under without project conditions are constrained such that they are always ≥ 0. Therefore, by definition, without project Delta inflow is always positive. However, for purposes of illustrating the bounds of water availability, it is assumed that without project Delta inflow "approaches zero" when without project Freeport inflow is zero.

Outside the typical irrigation season of April through August, without project Delta inflow was always positive. The frequency of water not being available for use in the study area during the irrigation season, i.e. without project Delta inflow approaches zero, is summarized in the second column of Table V.2. Without project Delta inflow is always positive in the months of April and May except in April 1977. The frequency of near-zero inflow in June, July and August is 10%, 25% and 5%, respectively.

Month	No Availability	Limited Availability	Unlimited Availability
April	<1	<1	>99
May	0	1	99
June	10	10	80
July	25	25	50
August	5	40	55

Table V.2. Frequency (%) of Water Availability for In-Delta Agriculture

Similar to Delta inflow, without project Delta outflow was always positive outside the typical irrigation season of April through August. The frequency of unlimited water availability for use in the study area during the irrigation season, i.e. without project Delta outflow is greater than or equal to zero, is summarized in the fourth column of Table V.2. Without project Delta outflow is always positive in the months of April and May except in April 1977, May 1976 and May 1992. The frequency of positive outflow in June, July and August is 80%, 50% and 55%, respectively.

The third column of Table V.2 provides an estimate of the frequency of limited water availability in the study area. This frequency is estimated such that the sum of columns 2, 3 and 4 equal 100%. As discussed in the previous paragraph, April and May is generally characterized by unlimited water availability. The frequency of limited availability in the months of June, July and August is 10%, 25% and 40%, respectively.

Frequency of water availability in the month of August is shown as an exceedance probability in Figure V.1. The top blue line shows the exceedance probability of without project Delta inflow. This line shows that the probability of inflow exceeding 0 cfs is 95%, i.e. inflow is near zero 5% of the time. This compares with the second column of Table V.2. Other values can be estimated from this figure. For example, the probability of inflow exceeding 5,000 cfs is 40%, i.e. inflow is less than 5,000 cfs 60% of the time. The bottom black line shows the exceedance probability of without project Delta outflow. This line shows that the probability of outflow exceeding 0 cfs is 55%. This compares with the fourth column of Table V.2.

The difference between water use and water availability in the study area was calculated on a monthly basis and averaged by month and 40-30-30 water year type. Results for the full period October 1921 through September 2012 are provided in Table V.3. These values are reported as a volume in thousand acre-ft per year and represent water use that exceeded water availability. The full period of record does not reflect the extent of excess water use under current conditions, given that the early period of record is characterized by lower upstream water use and higher without project Delta inflow. Therefore, results are also provided in Table V.4 and Figure V.2 for the more recent period October 1967 through September 2012.

WY Type	April	May	June	July	August	Total
Wet	0	0	0	5	0	6
Above Normal	0	0	0	48	17	65
Below Normal	0	0	18	65	45	128
Dry	0	0	36	95	65	196
Critical	4	3	54	101	83	244

Table V.3 Study Area Excess Use Using Inflow Criterion:
Water Years 1922-2012 Averages by Month and 40-30:30 Water Year Type (TAF)

WY Type	April	May	June	July	August	Total
Wet	0	0	0	9	0	9
Above Normal	0	0	0	48	0	48
Below Normal	0	0	40	101	18	159
Dry	0	0	90	126	85	300
Critical	6	4	78	126	106	320

Table V.4 Study Area Excess Use Using Inflow Criterion:
Water Years 1968-2012 Averages by Month and 40-30:30 Water Year Type (TAF)

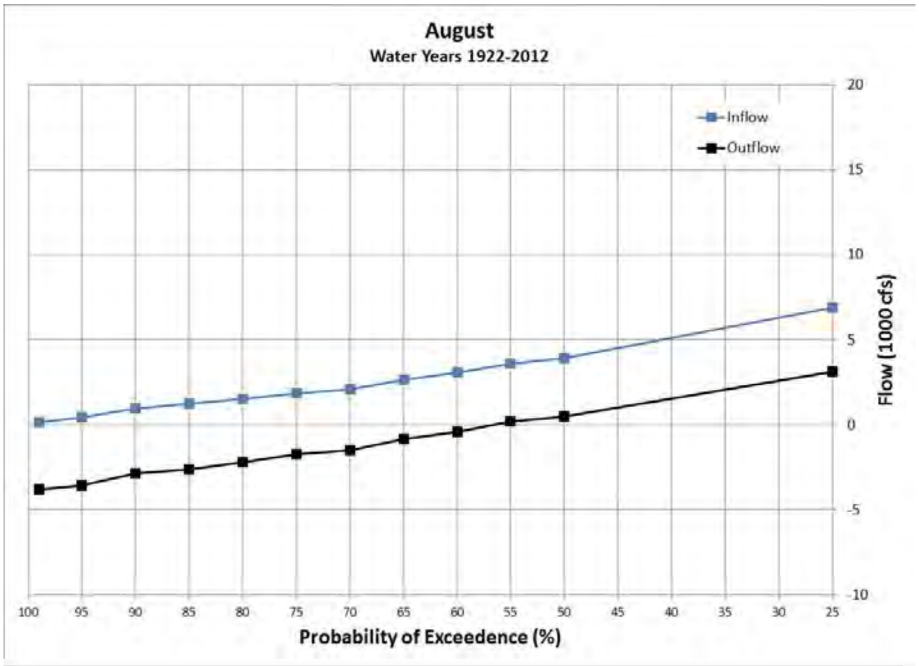


Figure V.1. Without Project Delta Inflow and Outflow Frequency During August:
Water Years 1922-2012

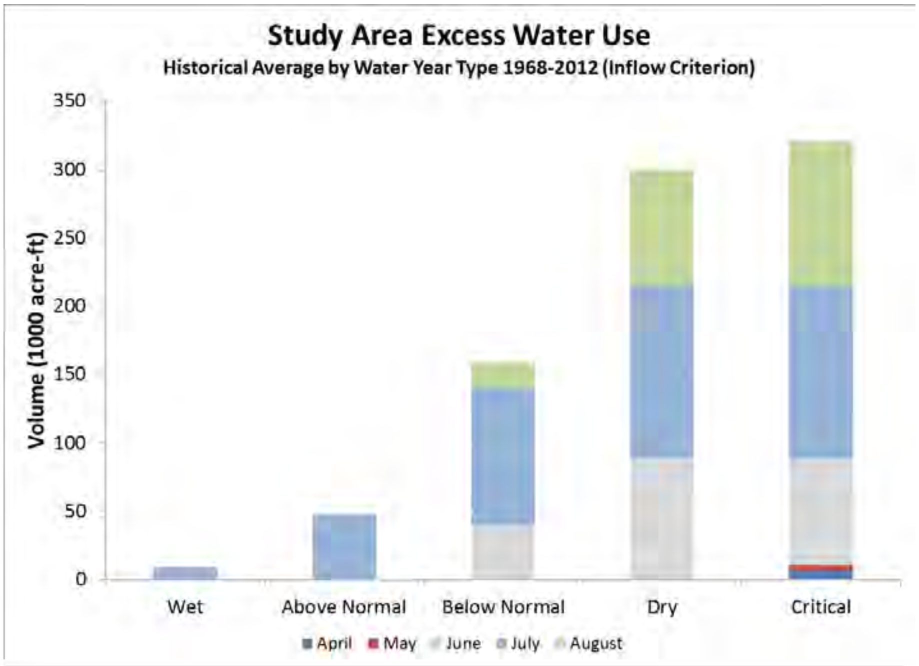


Figure V.2. Study Area Excess Diversion Using Inflow Criterion:
Water Years 1968-2012 Averages by Month and 40-30-30 Water Year Type (TAF)

.

VI. Analysis of Delta Water Quality (Salinity Criterion)

The previous section (Section V) evaluates the availability of surface water for agricultural use in the study area (i.e. south of the San Joaquin River) through a simple inflow approach or criterion. The evaluation assumes that when monthly Delta inflow approaches zero under a without project scenario, no water is available for in-Delta agricultural use and curtailment of all use in the study area is warranted. Furthermore, the evaluation assumes that if monthly Delta outflow is positive under a without project scenario, i.e. Delta inflow exceeds full in-Delta water use, water is available for all use in the study area and no curtailment is warranted. This latter assumption ignores circumstances when Delta outflow is positive but sufficiently small such that seawater intrusion impairs the beneficial use of water.

The purpose of this section is to evaluate the availability of surface water in the study area under without project conditions that is of adequate quality to meet agricultural beneficial uses. A water quality modeling analysis was conducted and is discussed below. An analysis of historical water quality measurements, prior to construction of the CVP and SWP projects, is summarized to provide a quasi-validation of the modeling results. Based on flow-salinity relationships suggested by the water quality modeling analysis, a conceptual approach to trigger water use curtailments as a function of hydrologic conditions is presented, i.e. the salinity criterion.

A. Water Quality Modeling Analysis

The availability of surface water in the study area under without project conditions that is of adequate quality to meet agricultural beneficial uses was evaluated through a water quality modeling analysis. This section summarizes the methods that were used to conduct the analysis and presents results from the modeling studies. Details on the modeling analysis are presented elsewhere (Tetra Tech Inc. 2015a).

1. Methods

The DSM2 model (Version 8.0.6) was used to simulate water quality in the study area under current and without project conditions. These scenarios were compared to assess how operation of the SWP and CVP influences salinity in the study area. Modeling assumptions associated with the scenarios are described below.

The current conditions scenario assumes an 82-year sequence (water years 1922-2003) of hydrology and operations provided in a recent SWP Delivery Reliability Report (DWR 2014). The without project scenario assumes no SWP-CVP Delta facilities (i.e. no export facilities and no Delta Cross Channel) and generally assumes the same upstream hydrology as the current conditions scenario; however, upstream hydrology is modified to remove SWP-CVP reservoirs. The method used to adjust upstream hydrology is similar to that described in Section V.

Note that the without project scenario assumes that upstream water use is identical to the current conditions scenario. In other words, the modeling assumption is that irrigated agriculture in the Sacramento Valley (and San Joaquin Valley) would have developed to the same level even if the SWP and CVP were unavailable to provide additional surface water supplies. The validity of this assumption is being tested through a separate C2VSim modeling study. The study will evaluate the physical and economic viability of utilizing groundwater when surface water is unavailable for irrigation, assuming historical development patterns absent the SWP-CVP projects.

The current conditions scenario assumes Vernalis salinity as characterized in the recent SWP Delivery Reliability Report (DWR 2014). It is recognized that current inflow to the Delta from the San Joaquin River is generally of higher salinity than during the era prior to construction of Friant Dam in the 1940s. While development impacts in the San Joaquin River basin are associated with several non-project facilities as well as CVP facilities, for purposes of this analysis it is assumed that water quality observed during the pre-Friant period is representative of the without project scenario. Thus, salinity in the San Joaquin River at Vernalis for this scenario is based on the report “Effects of the CVP upon the Southern Delta Water Supply” (USBR & SDWA 1980). Mathematical relationships developed in the 1980 report were used to (1) calculate salt load based on Vernalis flow, (2) convert salt load to chloride concentrations, and (3) convert chloride concentration to specific conductance or EC. These equations are provided in Appendix A for reference. Relative to current salinity conditions at Vernalis, this characterization results in fresher flow entering the Delta throughout the year except in the summer months and in the late spring of drier years (see Table VI.1).

Month	Monthly Average Salinity (mS/cm)									
	Wet		Above Normal		Below Normal		Dry		Critical	
	Current	w/o Projects	Current	w/o Projects	Current	w/o Projects	Current	w/o Projects	Current	w/o Projects
January	0.40	0.20	0.51	0.23	0.58	0.25	0.66	0.31	0.75	0.37
February	0.31	0.21	0.41	0.24	0.43	0.28	0.58	0.33	0.65	0.45
March	0.27	0.15	0.37	0.17	0.46	0.18	0.61	0.21	0.73	0.31
April	0.21	0.12	0.26	0.13	0.28	0.15	0.36	0.20	0.49	0.41
May	0.22	0.16	0.28	0.20	0.29	0.27	0.37	0.43	0.47	0.72
June	0.26	0.36	0.32	0.51	0.42	0.62	0.53	0.82	0.65	0.82
July	0.32	0.52	0.42	0.59	0.49	0.64	0.58	0.69	0.70	0.75
August	0.38	0.50	0.46	0.53	0.49	0.54	0.56	0.56	0.68	0.58
September	0.37	0.43	0.42	0.46	0.45	0.46	0.48	0.51	0.57	0.57
October	0.54	0.36	0.64	0.40	0.58	0.39	0.59	0.40	0.66	0.42
November	0.60	0.32	0.68	0.37	0.64	0.36	0.65	0.39	0.69	0.42
December	0.52	0.22	0.65	0.25	0.61	0.28	0.66	0.32	0.74	0.35

Table VI.1 Comparison of Vernalis Salinity under Current and Without Project Scenarios
by Month and Water Year Type: Water Years 1922-2002

2. Results

The Delta cannot be treated uniformly when evaluating responses to different impulses such as seawater intrusion, SWP-CVP project operations and Vernalis salinity boundary conditions. For example, water quality in the Old and Middle River corridors downstream of Clifton Court Forebay and Jones Pumping Plant are strongly influenced by project operations. In contrast, water quality in the remaining parts of the south Delta is primarily influenced by water quality at Vernalis and local groundwater and agricultural drainage (DWR 2005). Furthermore, the effect of seawater intrusion is not uniform throughout the Delta but is dictated to a large degree by a location's distance from Golden Gate.

Three stations in the study area were selected to illustrate salinity differences between the current condition and without project scenarios: (1) Old River @ Bacon Island (ROLD024), San Joaquin River @ Stockton (RSAC063), and Grant Line Canal @ Tracy Road Bridge. The Old River station, located along the Old and Middle River corridor, is strongly influenced by project operations. Of the three stations, the Old River location is closest to Golden Gate and is therefore most susceptible to seawater intrusion. The other stations are outside of the Old and Middle River corridor and are thus more strongly influenced by Vernalis water quality and local drainage conditions. Also, these locations are further from Golden Gate and therefore less susceptible to seawater intrusion.

Table VI.2 provides a broad qualitative interpretation of salinity differences between the current condition and without project scenarios for each location under wet and dry hydrologic conditions. Appendix B compares the two scenarios by location and month through frequency distribution charts. Table VI.2 denotes current conditions being more saline and less saline than the without project scenario by an "up" arrow (↑) and "down" arrow (↓), respectively. Similarity between the two scenarios is depicted by a dash (---). Non-irrigation season months are grayed out in the table. A rigorous numerical criterion was not followed to fill in the table; rather the comparison was accomplished through a visual inspection and should be interpreted in broad terms only. The frequency distribution charts in Appendix B provide a more precise quantitative comparison of the scenarios.

Old River @ Bacon Island shows a strong positive influence of the projects on water quality under most conditions. The projects, by maintaining higher Delta outflow, protect this station from severe seawater intrusion throughout the late spring thru fall under drier hydrologic conditions. Project operations result in minor salinity degradation during the winter (December-January) of drier years and the spring (April-May) of wetter years. However, this degradation is minor and does not impair beneficial uses of the water.

San Joaquin River @ Stockton shows a much weaker influence of the projects on water quality. Given this station's further distance from Golden Gate, the projects' maintenance of higher outflow has less influence on its water quality. However, benefits are observed in the summer (June-August) of drier years. This station typically shows salinity degradation under current conditions, relative to the without project scenario, during the non-irrigation season and in the early spring. As the Stockton station is highly sensitive to conditions in the San Joaquin River entering the Delta, most of this degradation is associated with higher Vernalis salinity. Vernalis salinity under current conditions is regulated to protect agricultural beneficial uses; therefore, degradation at this station does not result in beneficial use impairment.

Month	Old River @ Bacon Island		San Joaquin River @ Stockton		Grant Line Canal @ Tracy Rd. Bridge	
	Wet	Dry	Wet	Dry	Wet	Dry
January	---	↑	↑	↑	↑	↑
February	---	---	↑	↑	↑	↑
March	---	---	↑	↑	↑	↑
April	↑	---	↑	↑	↑	↑
May	↑	↓	↑	---	---	---
June	---	↓	---	↓	---	---
July	---	↓	---	↓	↓	---
August	---	↓	---	↓	↓	---
September	---	↓	---	---	---	---
October	---	↓	↑	↑	↑	↑
November	---	---	↑	↑	↑	↑
December	---	↑	↑	↑	↑	↑

Table VI.2. Change in Study Area Salinity under Current Conditions Relative to Without Project Scenario: Three Locations for Wet and Dry Hydrologic Conditions. The table denotes current conditions being more saline and less saline than the without projects scenario by an "up" arrow (↑) and "down" arrow (↓), respectively. Similarity between the two scenarios is depicted by a dash (---).

In broad terms, Grant Line Canal @ Tracy Road Bridge exhibits a similar water quality response as seen at Stockton. This station is also strongly influenced by water quality conditions at Vernalis. Given this station's distance from Golden Gate, seawater intrusion would rarely be experienced and therefore, project operations during dry years do not provide a noticeable water quality benefit at this station.

B. Observed Water Quality Analysis

The DSM2 hydrodynamic and water quality modeling analysis discussed in the previous section shows periods of dramatic salinity intrusion into the central and southern Delta. Such conditions have not been observed in recent history due to the operation of the SWP-CVP upstream reservoirs and Delta facilities. Although the modeled conditions were hypothetical in that the specific without project hydrology did not occur historically, periods of dramatic salinity intrusion into the central and southern Delta are not without precedent. This section summarizes work that was conducted to evaluate salinity data that were collected in the study area in the 1920s through 1940s prior to the construction of Shasta Dam and other upstream project reservoirs (Tetra Tech Inc. 2015b). These data show that the study area was subject to severe seawater intrusion, even during this early period before agriculture in the Sacramento River basin was fully developed.

1. Methods

This analysis of historical interior Delta salinity builds on an analysis of salinity trends in the western Delta (Hutton et al. 2015, Tetra Tech Inc. 2014). The western Delta salinity trend analysis was based on all available data from water years 1922-2012, collected by various state and federal entities. As part of this earlier effort, salinity data in scanned paper reports from DWR and its predecessor entity, Department of Public Works were digitized and integrated with modern data from the California Data Exchange Center (CDEC) into a single database. Because the focus of this earlier effort was on the western Delta, CDEC data were compiled only from relevant stations. However, all salinity data (both western Delta and interior Delta stations) were scanned and digitized as part of the effort.

Similar to the earlier western Delta effort, appropriate data cleaning methodologies were applied to the historical interior Delta data to develop a monthly data set to evaluate salinity changes over the past nine decades. Maps were developed for specific hydrologic conditions and time periods, by developing averages and other statistical metrics of the available data, and by interpolating across the Delta channels. Statistical analyses of trends at key locations were performed to support interpretation of the maps.

Data are presented as maps over different time intervals (1922-1944; 1945-1967; and 1968-2012), given similar ranges in the position of the X2 isohaline and San Joaquin River flows. Maps are presented for salinity aggregated as the mean, 25th percentile, median (50th percentile), and the 75th percentile. In general the maps show the intrusion of salinity into the central and southern Delta when X2 values are high and especially when San Joaquin River flows are low. For the cases where salinity intrusion occurs, and given similar hydrology, the 1922-1944 salinities are often different from 1945-1967 and 1968-2012 periods.

Box plots were used to summarize the data shown in maps. As expected, summer specific conductance values are higher than spring values, although the magnitude of the difference varies by region. There are also differences of specific conductance over the time intervals considered: areas typically in the western portion of the study domain show decreases over the period, and in the south, show small increases.

Observed salinity data were averaged in preparation for presentation on maps and were classified into different groups that were characteristic of the season and hydrology. A monthly average specific conductance was calculated for each station and month. For the grab sample-based data, this was simply the average of all the observations in a given month. For the continuous CDEC data, hourly and 15-minute data were averaged to the daily level. In this averaging process, if at least 50% of the possible values in a day (12 observations for hourly data or 48 observations for 15-minute data) were missing, the daily average was also identified as missing. On each date the non-missing value with the largest original time resolution (daily > hourly > 15 minute) is kept for monthly averaging. The monthly average is also undefined if more than 50% of the days in the month are missing. Once the monthly averages were calculated, they were split into subsets based on four categories:

- Monthly San Joaquin River X2 position. Three San Joaquin River X2 categories were defined: (1) < 54 km, (2) 54-82 km, and (3) > 82 km. Gaps in the time series, as calculated in the 2014 report, were generally filled through linear interpolation.
- Season. Two seasonal categories were defined: (1) Spring (April-June) and Summer (July-September).
- Vernalis flow. Two Vernalis flow categories were defined: (1) above or (2) below the median flow (to the nearest 1,000 cfs) within each season.
- Time period. Three time periods were defined: (1) WYs 1922-1944, (2) WYs 1945-1967, and (3) WYs 1968-2012. The mean as well as the 25th, 50th, and 75th percentiles of the monthly averages were evaluated for each subset.

2. Results

Maps were compiled in Tetra Tech Inc. (2015b) by method of data aggregation (mean, 25th percentile, 50th percentile, and 75th percentile). In general the maps show intrusion of salinity into the central and southern Delta when X2 values are high and especially when San Joaquin River flows are low. The analysis clearly shows how the distribution of interior Delta salinity in the summer months has changed following the construction and operation of Shasta Dam.

Three maps (Figures VI.1 thru VI.3) are illustrative of the suite of maps provided in the 2015 report. The maps clearly show that salinity intrusion into the study area was severe prior to the operation of upstream project reservoirs and resulted in conditions that were unfavorable to agricultural beneficial uses. While not an exact match, the salinity distribution resembles that provided in the without project DSM2 simulation.

Box and whisker plots (Figures VI.4 and VI.5) illustrate additional analyses provided in the 2015 report. These sample figures demonstrate that, although the without project conditions were characterized by more severe seawater intrusion events, the seawater intrusion was not universal throughout the entire study area. In particular, locations that were strongly influenced by conditions along the San Joaquin River at Vernalis were typically less salty under without project conditions than under current conditions. As noted previously in this document, under similar hydrologic conditions, Vernalis salinity was lower prior to development of CVP projects upstream of Vernalis. Again, while not an exact match, these findings are in line with those provided in the without project DSM2 simulation.

C. Water Availability Analysis Using the Salinity Criterion

Section V evaluated the availability of surface water for agricultural use in the study area utilizing the inflow criterion. The approach effectively used Delta inflow as a "trigger" for imposing curtailments by assuming that water was available for diversion in the study area only when Delta inflows was positive. As noted previously, the inflow criterion does not account for circumstances when seawater intrusion is sufficiently severe to impair beneficial use of available water. The purpose of this section is to evaluate the availability of surface water in the study area under without project conditions that is of adequate quality to meet agricultural beneficial uses. This salinity criterion provides an approach to trigger water use curtailments as a function of hydrologic conditions. It is envisioned that the following methodology will be refined to develop a real time approach for informing decisions on water use curtailment in the study area. Methods and results based on the proposed methodology are provided below.

1. Methods

The proposed salinity criterion methodology is summarized below in four steps. The methodology requires the specification of a salinity "trigger"; this trigger is a salinity value that is defined as the maximum salinity that can be put to beneficial use. Given the study area's assumed response to seawater intrusion, the methodology identifies irrigated lands that are subject to salinity impairment for a given hydrologic condition.

The methodology was applied using two separate approaches. One approach (Approach 1) assumes that water quality simulation results are available from DSM2 or another water quality model. The second approach (Approach 2) assumes that water quality simulation results are not available and utilizes flow-salinity relationships to estimate the extent of salinity intrusion in the study area. Both approaches are discussed below.

a) Antecedent Outflow

Seawater intrusion is influenced by hydrologic conditions in general and the time history of Delta outflow in particular. This time history was mathematically defined by Denton (1993) and termed antecedent outflow. Antecedent outflow, G, is defined by the following routing function similar to a relationship used by Harder (1977):

$$\frac{\partial G}{\partial t} = \frac{(Q - G) * G}{\beta} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (VI.1)$$

where Q is Delta outflow and β is an empirically determined constant. As Denton (1993) points out, the term β/G governs the rate at which G approaches steady state.

Approach 1 utilizes salinity estimates produced by DSM2 simulations and therefore does not rely on antecedent outflow estimates. Approach 2, on the other hand, requires antecedent outflow estimates. This analysis calculated an end-of-month (rather than average month) antecedent outflow assuming monthly average outflow from the DSM2 without project scenario and a nominal β value of 5710 cfs-months. Possible analysis refinements include (1) calibrating the β constant to provide a better fit to DSM2 salinity data in the study area and (2) conducting the analysis on a daily time step.

b) Delta Salinity Gradient

Approach 1 utilized DSM2 salinity data to directly characterize the salinity gradient in the study area. Approach 2 adopted the Delta Salinity Gradient (DSG) modeling approach (Hutton et al. 2015, Hutton 2014) to mathematically describe how far upstream a salinity isohaline travels into the study area as a function of antecedent outflow. DSG model equations (Equations VI.2 and VI.3) were calibrated with DSM2 data from the without project scenario for three river reaches in the study area. The calibration assumed an index salinity distance (X2) defined by a 2.0 mS/cm surface isohaline[2] (Tetra Tech 2015a). The three river reaches – Old, Middle and San Joaquin – are shown in Figure VI.6. Calibrated model constants are provided for each river reach in Table VI.3.

$$X = X2 * \left[\frac{\ln\left(\frac{S - S_b}{S_o - S_b}\right)}{\tau}\right]^{-\Phi_2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (VI.2)$$

$$X2 = \Phi_1 * G^{\Phi_2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (VI.3)$$

where:

X = distance of salinity isohaline (S) from Golden Gate in km

X2 = distance of index salinity isohaline (2.0 mS/cm surface) from Golden Gate in km; this definition differs from the conventional definition of X2

S = salinity isohaline in mS/cm, defined as the salinity "trigger" or the maximum salinity that can be put to beneficial use

G = antecedent outflow in cfs

S_o, S_b, Φ_1 and Φ_2 = calibrated model constants

---

[2] The assumed 2.0 mS/cm index differs from the conventional 2.64 mS/cm surface isohaline associated with a 2 ppt bottom salinity.

$$\tau = \ln\left[\frac{2.0 - S_b}{S_o - S_b}\right]$$

River Reach	Φ_1	Φ_2	S_o (mS/cm)	S_b (mS/cm)
Old River	696	-0.234	24.7	0.38
Middle River	624	-0.221	24.6	0.44
San Joaquin River	465	-0.187	24.7	0.34

Table VI.3. DSG Model Constants for Study Area River Reaches

c) *Curtailment Area & Volume*

Relationships between channel distance and cumulative downstream area were developed for the three river reaches – Old, Middle and San Joaquin – within the study area (Tetra Tech 2015a); the same relationships were employed by Approaches 1 and 2. These relationships allow for the estimation of isohaline location and total area downstream of a prescribed salinity trigger, i.e. the curtailment area. These relationships are provided as a map in Figure VI.7 and as lookup tables in Appendix C. Thus, by defining a salinity trigger, the curtailment area can be calculated for any hydrologic condition.

Once the curtailment area is estimated, the curtailment volume can be estimated over a given time interval:

$$Curtailment\ Volume = \frac{A_{curtail} * Q_{ncd}}{A_{delta}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (VI.4)$$

where $A_{curtail}$ is the curtailment area in acres, Q_{ncd} was previously defined as Delta net channel depletions in acre-feet, and A_{delta} was previously defined as the total irrigated area of the Delta = 393,400 acres. This calculation step is only defined when $Q_{ncd} > 0$. This estimate could be refined through modeling analysis using the Delta Island Consumptive Use (DICU) model.

2. Results

Following the methodology outlined above and assuming a salinity trigger of 2.0 mS/cm, curtailment area and volume were calculated for every month over the period October 1921 through September 2012 utilizing the hydrology developed in Section V.

The curtailment volume was calculated on a monthly basis and averaged by month and 40-30-30 water year type. Results are provided for Approach 1 (DSM2 estimates) in Table VI.4 and for Approach 2 (DSG estimates) in Table VI.5. These values, reported as a volume in thousand acre-ft per year, represent water use that occurred when salinity exceeded the assumed salinity trigger. The full period of record does not reflect the extent of potential curtailment, given that the early period of record is characterized by lower upstream water use and higher without project antecedent outflow. Therefore, results are also provided in Table VI.6 and Figure VI.8

(Approach 1) and Table VI.7 and Figure VI.9 (Approach 2) for a more recent period following October 1967.

WY Type	June	July	August	September	October	November	Total
Wet	0	0	0	0	0	0	1
Above Normal	0	2	5	2	0	0	9
Below Normal	0	4	17	6	1	0	28
Dry	1	15	37	16	5	0	74
Critical	9	41	50	25	13	2	141

Table VI.4 Study Area Excess Use Using 2.0 mS/cm Salinity Criterion (Approach 1): Water Years 1922-2002 Averages by Month and 40-30:30 Water Year Type (TAF)

WY Type	June	July	August	September	October	November	Total
Wet	0	0	0	0	0	0	1
Above Normal	0	1	3	0	0	0	5
Below Normal	1	7	17	3	0	0	28
Dry	1	18	36	8	1	0	64
Critical	5	34	53	22	7	0	122

Table VI.5 Study Area Excess Use Using 2.0 mS/cm Salinity Criterion (Approach 2): Water Years 1922-2012 Averages by Month and 40-30:30 Water Year Type (TAF)

WY Type	June	July	August	September	October	November	Total
Wet	0	0	0	0	0	0	1
Above Normal	0	1	2	0	0	0	3
Below Normal	0	8	31	12	0	0	51
Dry	3	25	54	20	3	0	104
Critical	9	43	58	30	16	3	160

Table VI.6 Study Area Excess Use Using 2.0 mS/cm Salinity Criterion (Approach 1): Water Years 1968-2002 Averages by Month and 40-30:30 Water Year Type (TAF)

WY Type	June	July	August	September	October	November	Total
Wet	0	1	0	0	0	0	1
Above Normal	0	1	1	0	0	0	2
Below Normal	1	14	25	5	0	0	45
Dry	3	41	64	13	1	0	122
Critical	8	52	78	32	10	0	179

Table VI.7 Study Area Excess Use Using 2.0 mS/cm Salinity Criterion (Approach 2): Water Years 1968-2012 Averages by Month and 40-30:30 Water Year Type (TAF)

The curtailment volume estimates differ from those provided in Section V because these estimates are based on a salinity trigger, whereas the previous estimates are based on a Delta inflow trigger. It is worthwhile to note the seasonal lag associated with the curtailment volumes estimated from the salinity criterion. Curtailments based on the inflow criterion are limited to the spring and summer months (April – August) whereas curtailments based on the salinity criterion are limited to the summer and fall months (typically June – November). This difference is reasonable given that salinity intrusion is affected by the time history of Delta outflow.

D. Quasi-Validation of Water Quality Modeling

It is recognized that the extremely low Delta outflow conditions associated with the without project scenario are outside the calibration range of the DSM2 model. To assess model validity under these conditions, the historical salinity data were compared with simulation results. This comparison is not purported to be a true model validation, as no attempt was made to model the actual hydrologic, hydrodynamic, topographic and bathymetric conditions that existed during the period when data were collected. A true model validation is complicated by the spatial and temporal sparseness of historical observations in the study area.

Figure VI.10 provides graphical comparisons of salinity observations and model predictions at two locations in the study area. The first three graphs (a)-(c) show results along Middle River at or near a location currently identified by the RKI RMID015. The final graph (d) shows results along Old River at or near a location currently identified by the RKI ROLD024. All graphs compare observed data (black squares) with the DSM2 without project simulation results described previously (blue line), the applicable DSM2-calibrated DSG model predictions (red line) utilizing historical (DAYFLOW) hydrology, and a DSM2 simulation utilizing historical hydrology (black line). These comparisons suggest that although the DSM2 historical simulation does not demonstrate a consistent prediction bias, the DSM2-calibrated DSG model is likely under-representing seawater intrusion into the study area under extremely low outflow conditions. Furthermore, these comparisons demonstrate that the without project hydrology results in much greater seawater intrusion than experienced in the 1920s and 1930s due to greater water use upstream of the Delta.

Figure VI.10 (a) compares observed and modeled salinity during the summer and fall of 1924, one of the driest periods on record for the Central Valley. If a “perfect” DSM2 simulation was produced and a “perfect” DSG fit to the simulation results were performed, we would expect the red line to match the time trajectory of the observed data. The DSG model clearly under-estimates salinity intrusion into Middle River during this period. Furthermore, the observed data suggests that the peak salinity occurs in October rather than in September, as suggested by the DSG predictions and the DSM2 without project simulation. Similar observations are made at the Middle River location during the summer and fall of 1931and 1934 (graphs (b) and (c)) as well as the Old River location during the summer and fall of 1931 (graph (d)).

Figure VI.11 compares observed and modeled salinity gradients in the study area under a range of low antecedent outflow conditions. The figure shows the salinity gradient relative to distance from Golden Gate in units of kilometers. The top left chart shows the salinity gradients for an outflow range of 500-1000 cfs; the bottom right chart shows the salinity gradients for an outflow range of 4000-4500 cfs. Observed data span water years 1922-44 and are shown as box and whisker plots. Modeled data are represented by the DSM2-calibrated DSG models for the San Joaquin, Old and Middle River reaches in the study area. The figure demonstrates that the model captures the approximate shape of the observed salinity gradient and is consistent with the observations associated with Figure VI.10, i.e. the DSG models appear to under-estimates salinity intrusion into the study area. Based on these consistent observations, this analysis concludes that the use of DSM2 and the DSM2-calibrated DSG models as part of the proposed salinity criterion methodology allows for a reasonable and conservative method of evaluating water supply availability in the study area.

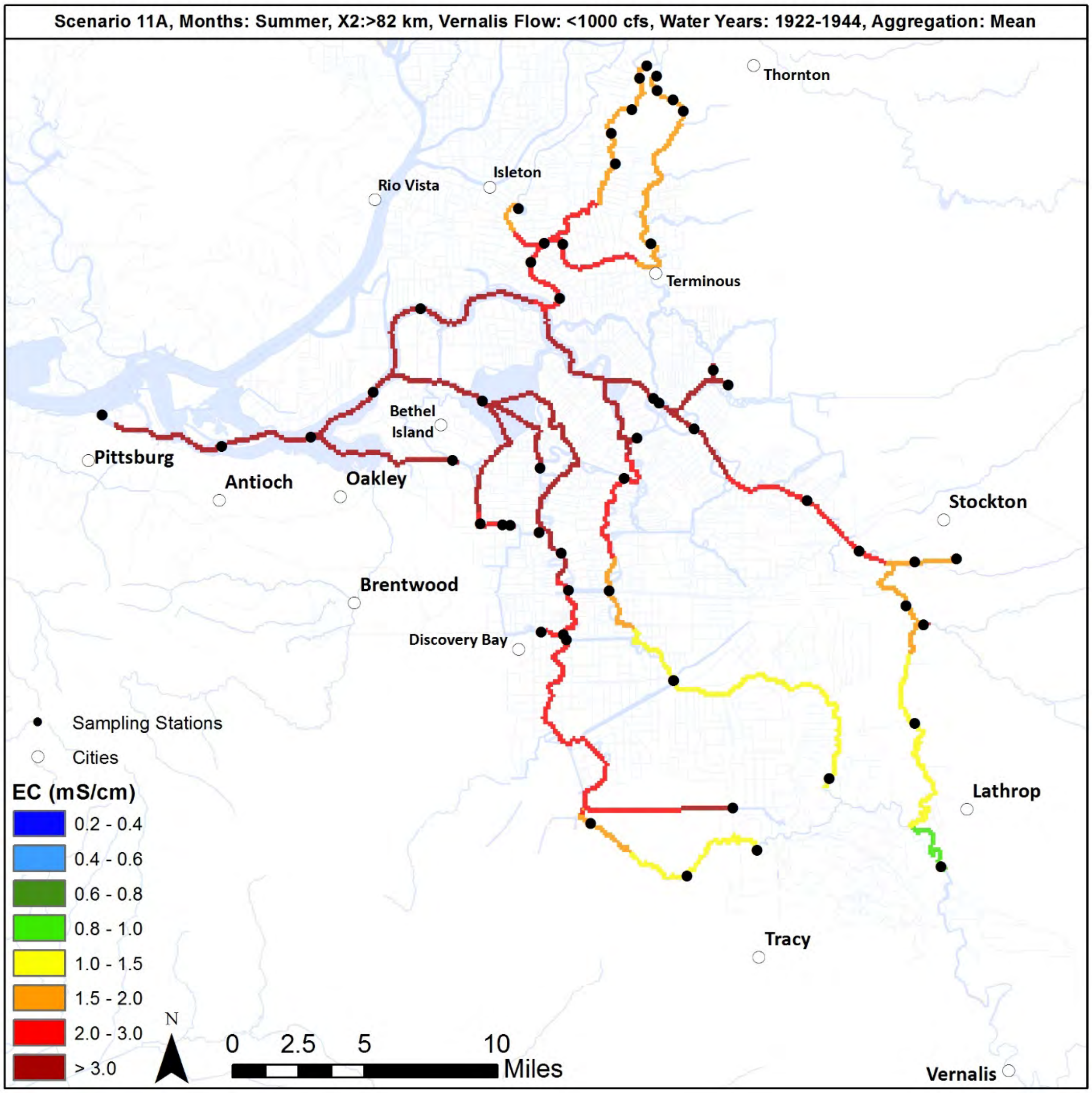


Figure VI.1 Mean Salinity Distribution in the Study Area for Water Years 1922-44: X2 > 82 km; Summer Season; Vernalis Flow < 1000 cfs (from Tetra Tech Inc. 2015b)

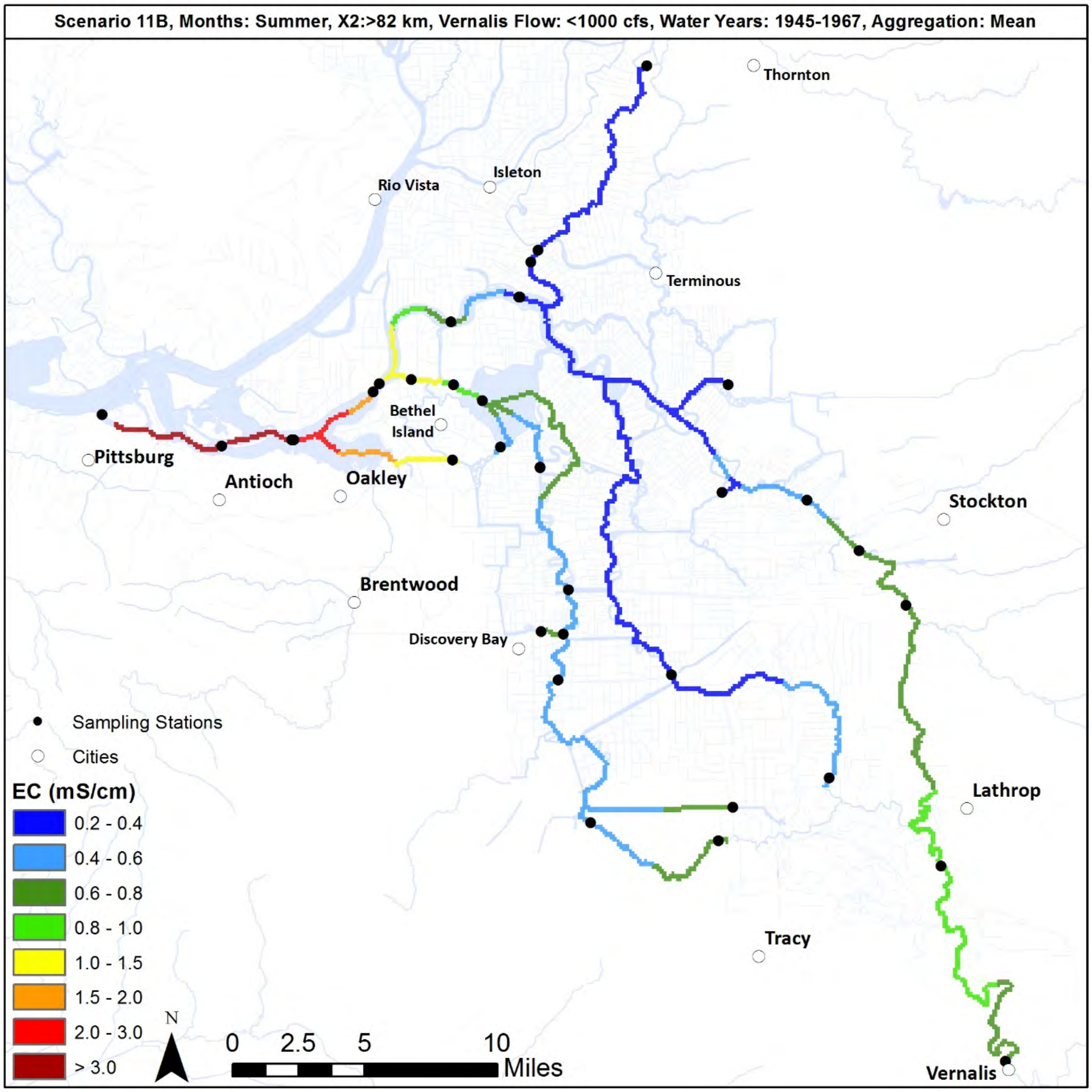


Figure VI.2 Mean Salinity Distribution in the Study Area for Water Years 1945-67: X2 > 82 km; Summer Season; Vernalis Flow < 1000 cfs (from Tetra Tech Inc. 2015b)

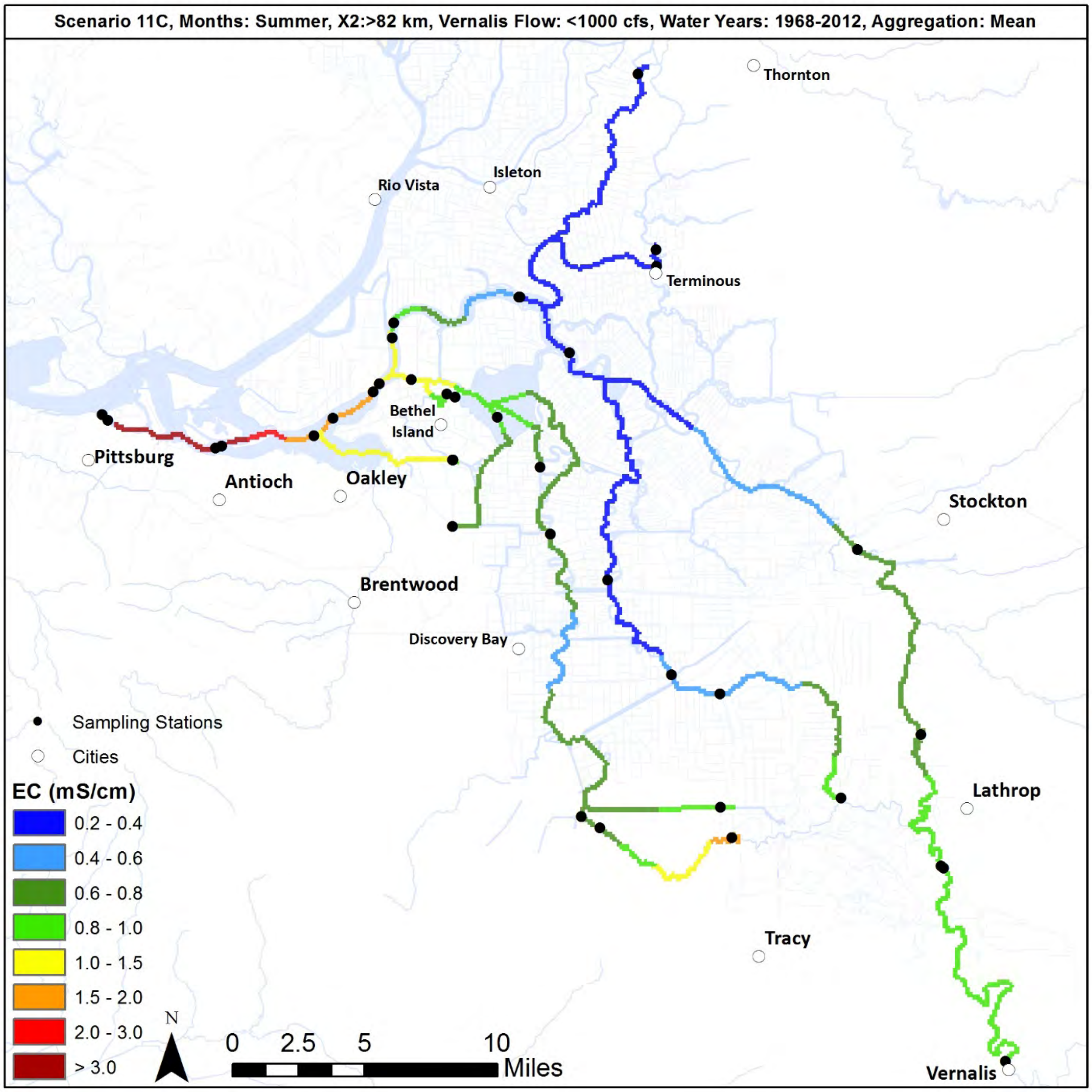


Figure VI.3 Mean Salinity Distribution in the Study Area for Water Years 1968-2012: X2 > 82 km; Summer Season; Vernalis Flow < 1000 cfs (from Tetra Tech Inc. 2015b)

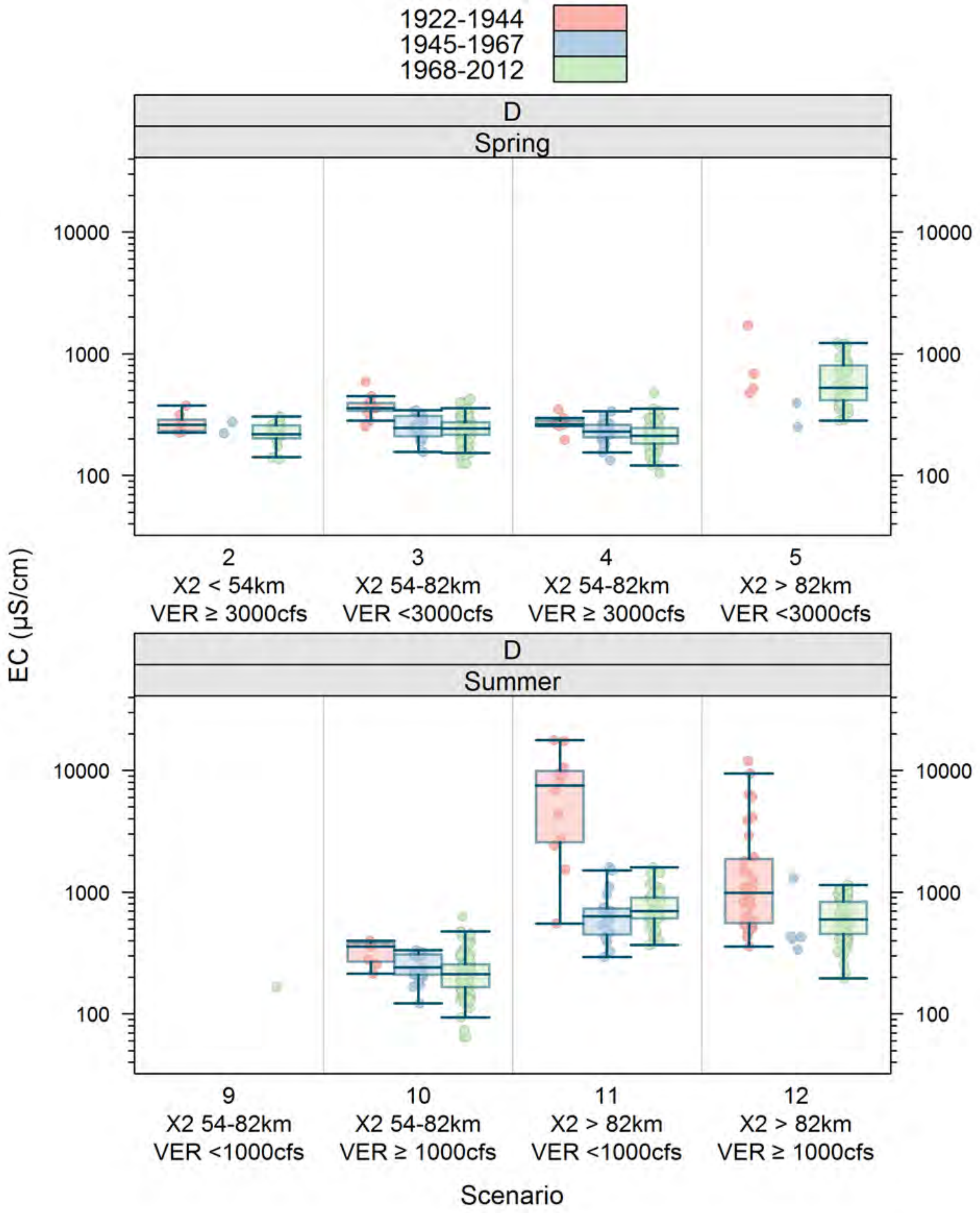


Figure VI.4. Box and Whisker Plots Comparing Monthly Average Salinity in the Vicinity of Franks Tract and Old River Downstream of Bacon Island for Three Time Periods (from Tetra Tech Inc. 2015b)

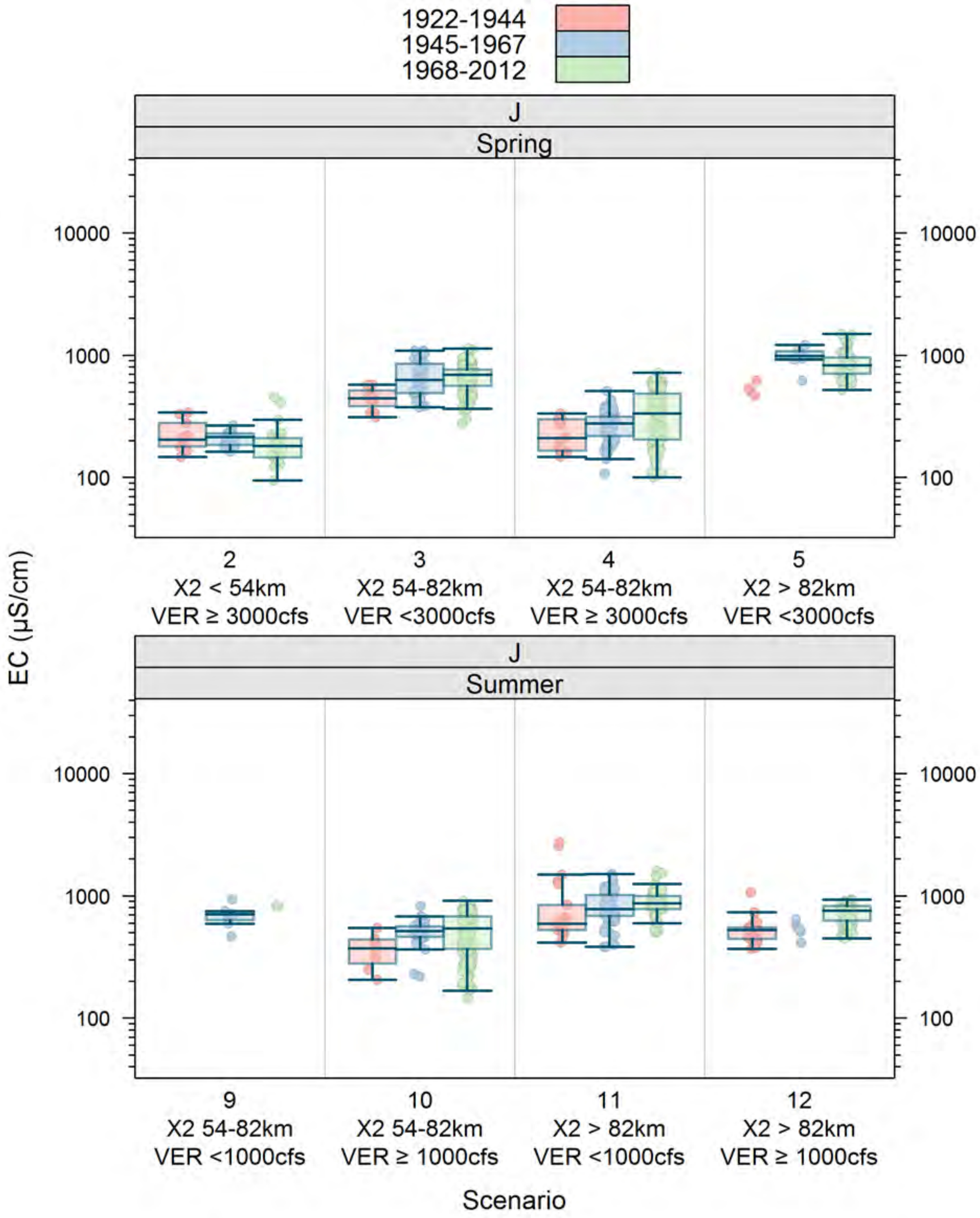
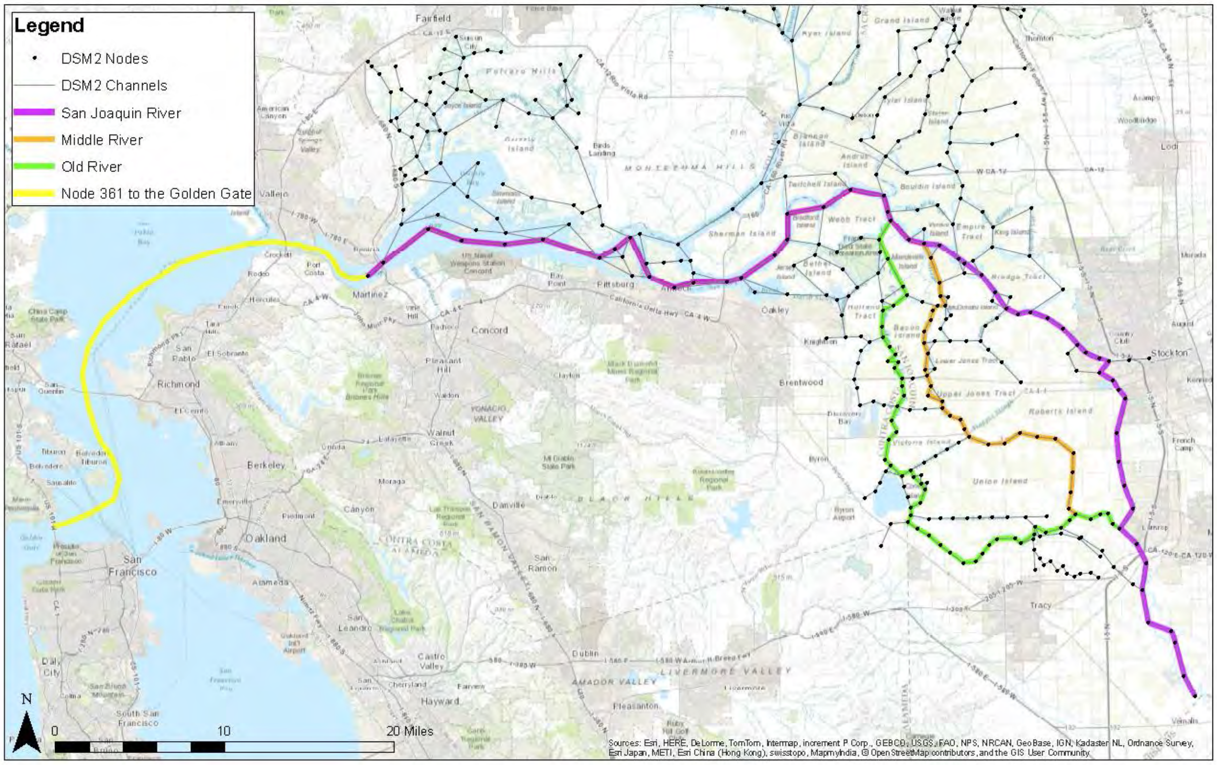
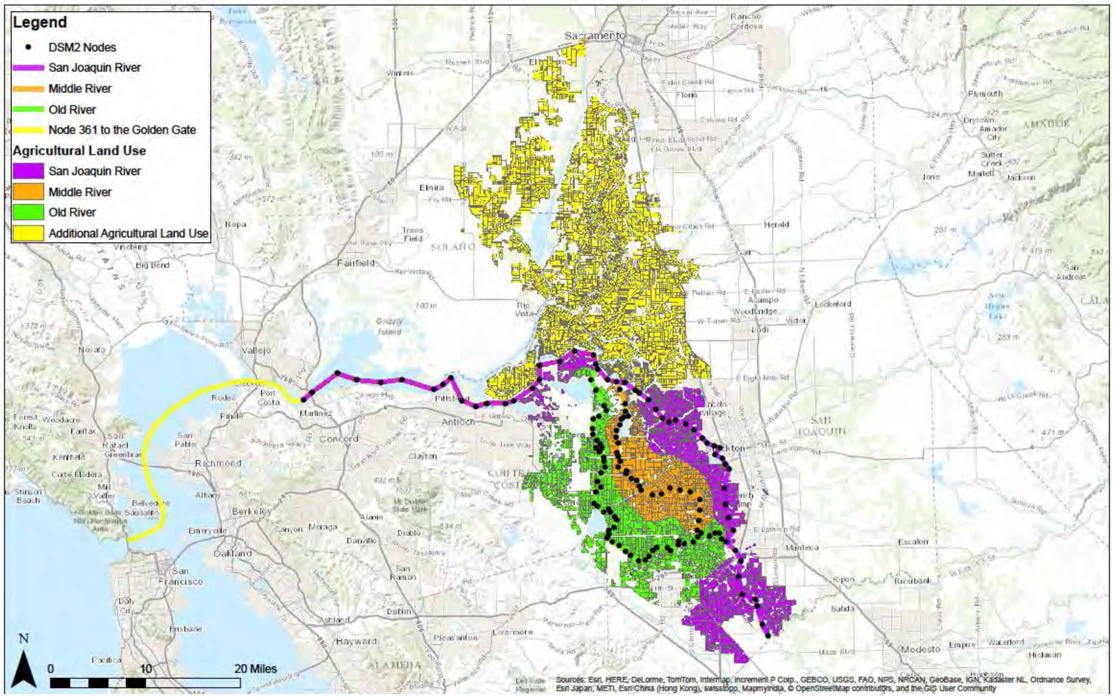


Figure VI.5. Box and Whisker Plots Comparing Monthly Average Salinity along the San Joaquin River between Vernalis and Stockton for Three Time Periods (from Tetra Tech Inc. 2015b)



Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, Mapmyindia, © OpenStreetMap contributors, and the GIS User Community.

Figure VI.6 Study Area River Channels Utilized in Salinity Criterion Analysis



Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, Mapmyindia, © OpenStreetMap contributors, and the GIS User Community

Figure VI.7 Assumed Relationship Between Study Area Diversions and River Reach

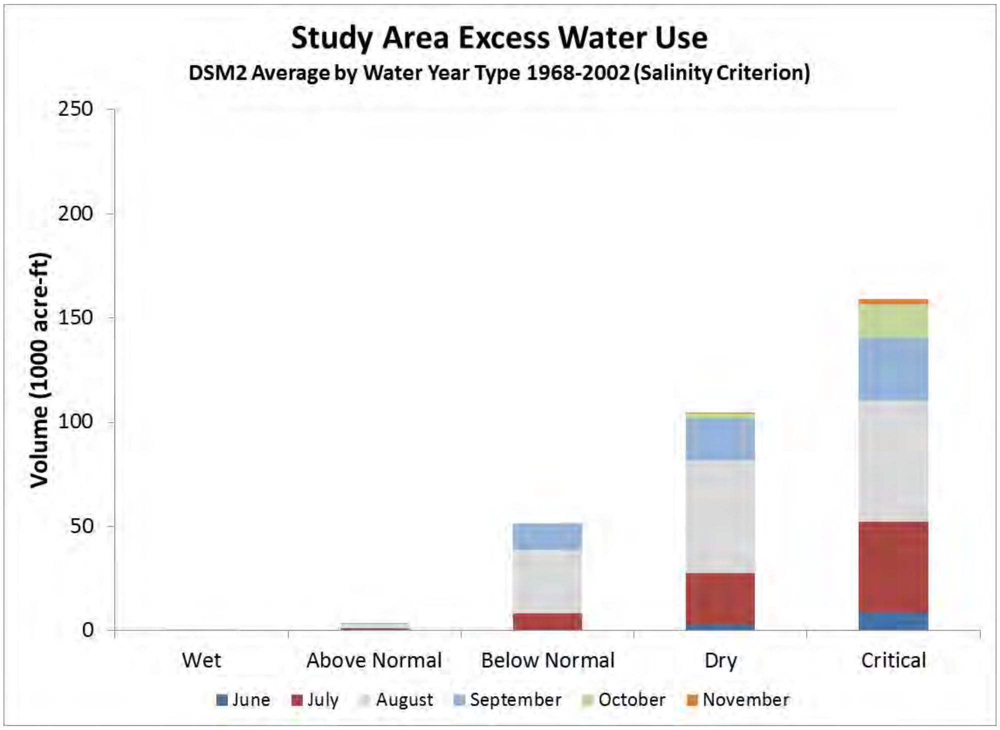


Figure VI.8 Study Area Excess Diversion Using 2.0 mS/cm Salinity Criterion (Approach 1): Water Years 1968-2003 Averages by Month and 40-30-30 Water Year Type (TAF)

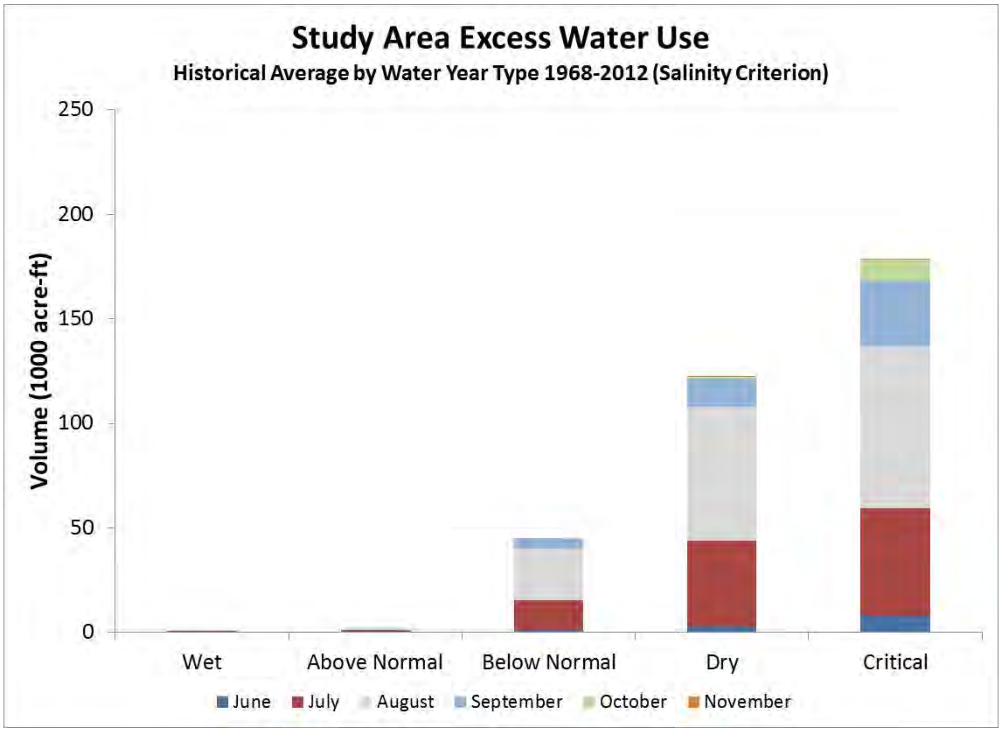
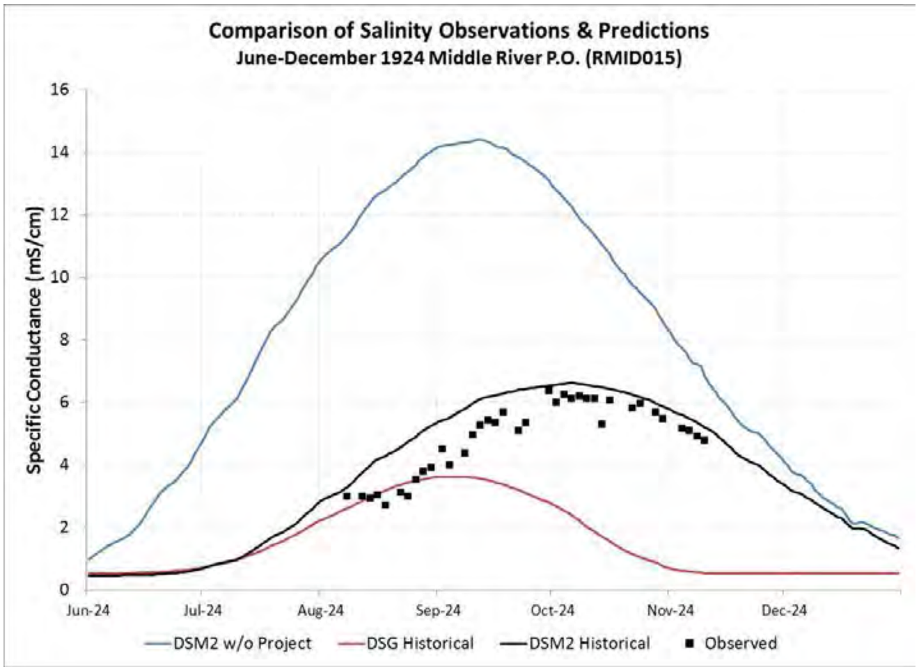


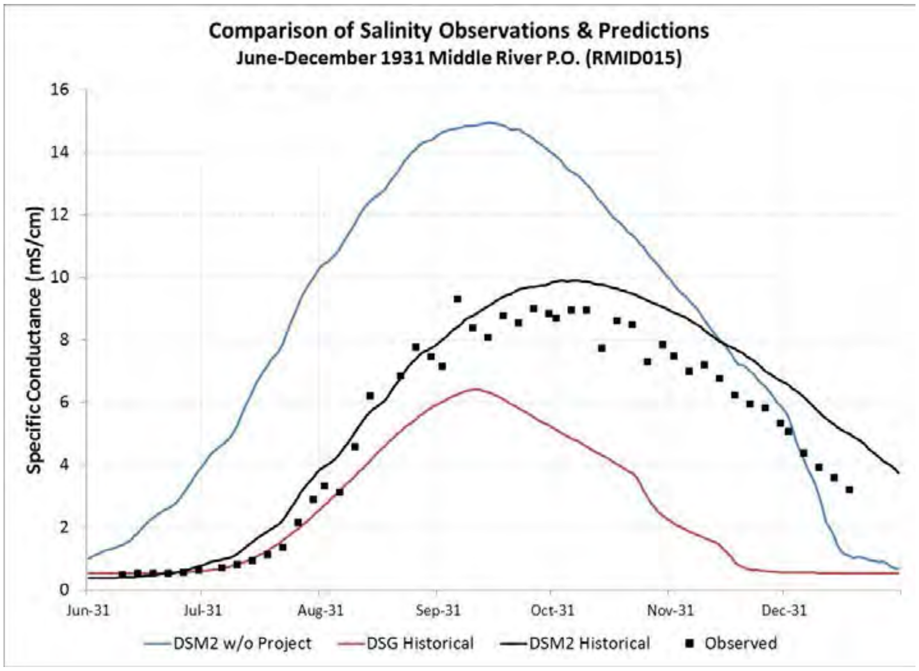
Figure VI.9 Study Area Excess Diversion Using 2.0 mS/cm Salinity Criterion (Approach 2): Water Years 1968-2012 Averages by Month and 40-30-30 Water Year Type (TAF)

Figure VI.10 Comparison of Salinity Observations & Predictions

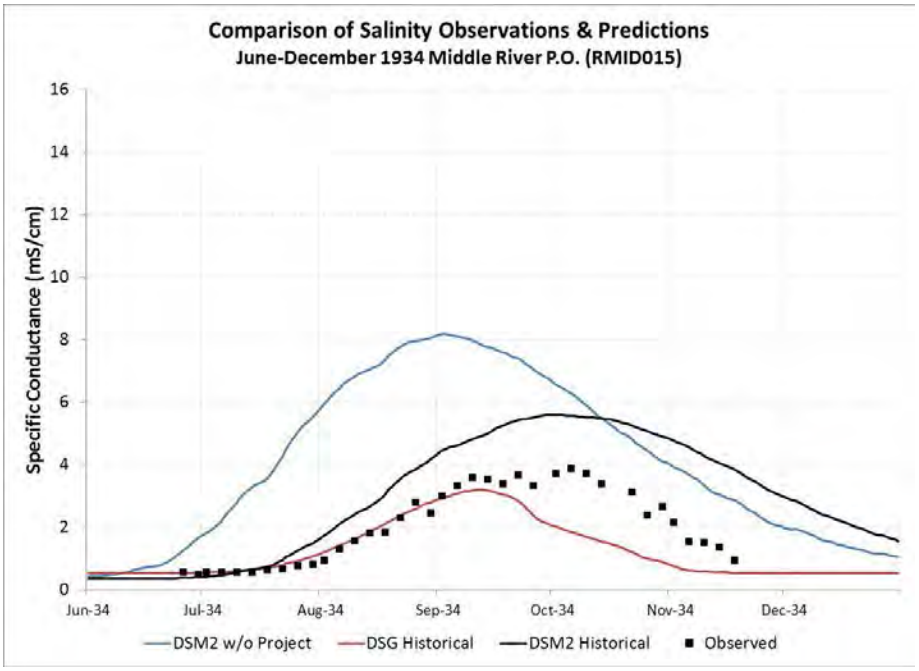
(a)



(b)



(c)


Comparison of Salinity Observations & Predictions
June-December 1934 Middle River P.O. (RMID015)
Specific Conductance (mS/cm)
0
2
4
6
8
10
12
14
16
Jun-34
Jul-34
Aug-34
Sep-34
Oct-34
Nov-34
Dec-34
DSM2 w/o Project
DSG Historical
DSM2 Historical
Observed

(d)

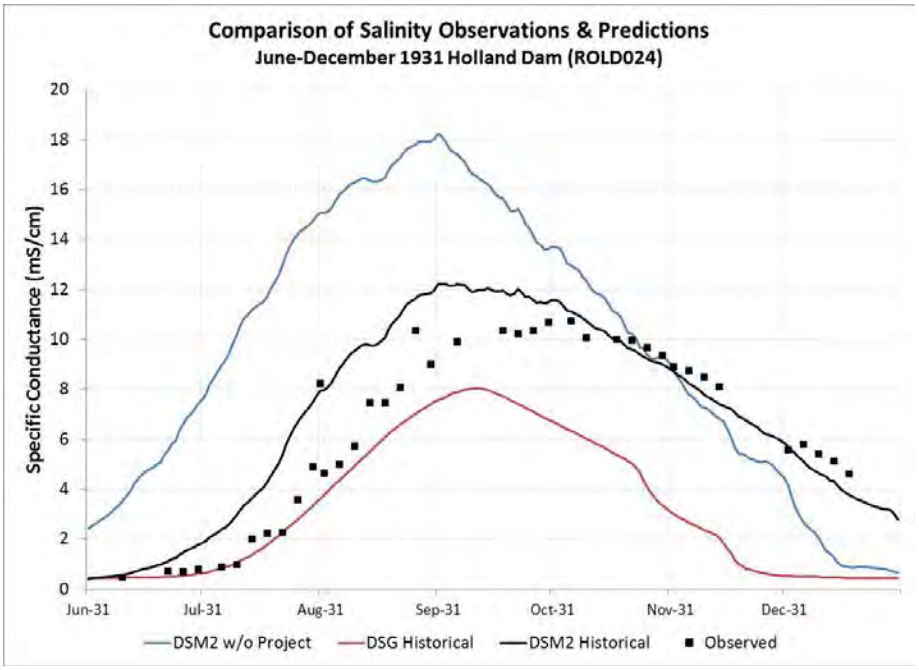
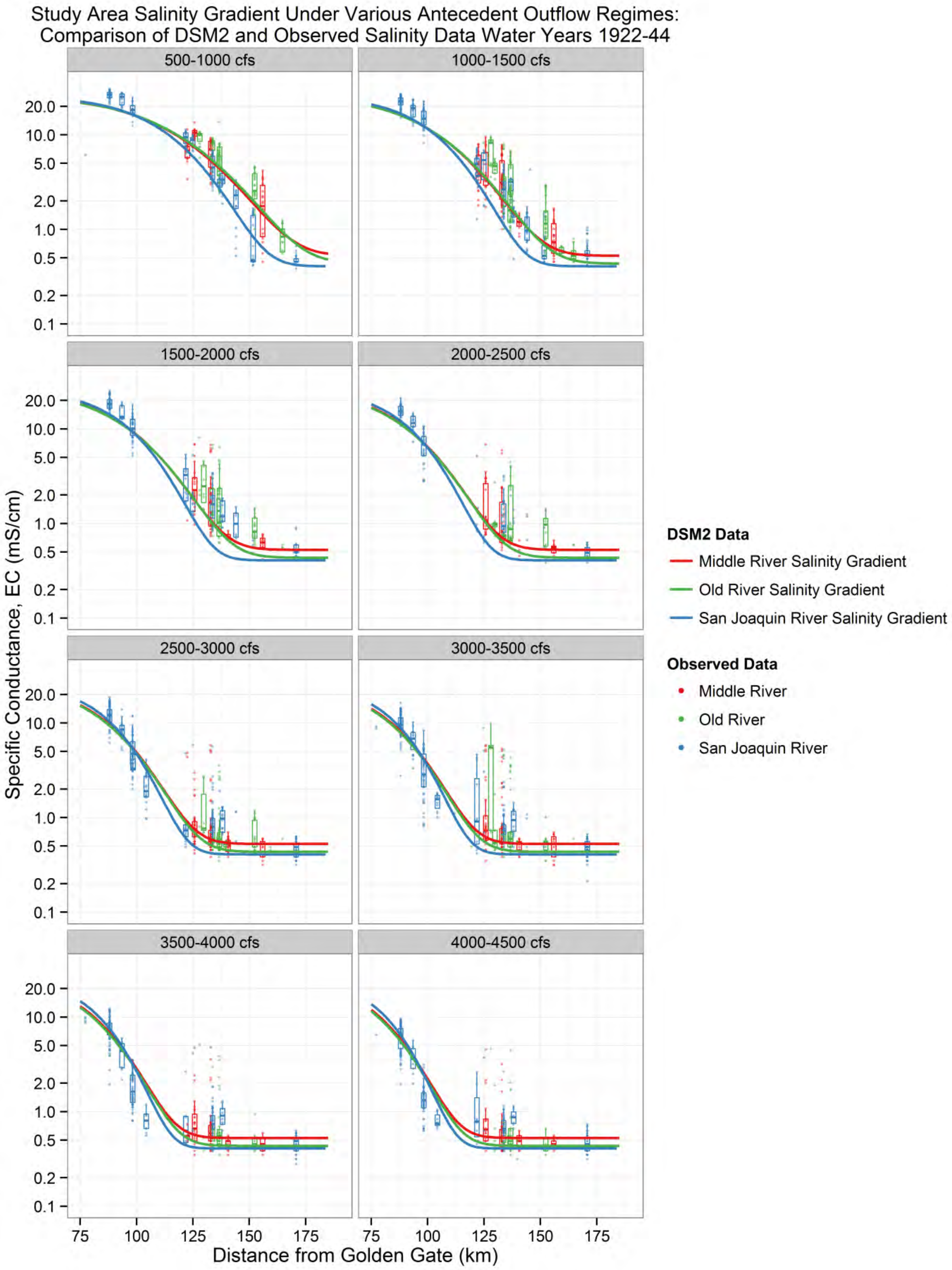

Comparison of Salinity Observations & Predictions
June-December 1931 Holland Dam (ROLD024)
Specific Conductance (mS/cm)
0
2
4
6
8
10
12
14
16
18
20
Jun-31
Jul-31
Aug-31
Sep-31
Oct-31
Nov-31
Dec-31
DSM2 w/o Project
DSG Historical
DSM2 Historical
Observed

Figure VI.11


Study Area Salinity Gradient Under Various Antecedent Outflow Regimes:
Comparison of DSM2 and Observed Salinity Data Water Years 1922-44
500-1000 cfs
1000-1500 cfs
1500-2000 cfs
2000-2500 cfs
2500-3000 cfs
3000-3500 cfs
3500-4000 cfs
4000-4500 cfs
Specific Conductance, EC (mS/cm)
20.0
10.0
5.0
2.0
1.0
0.5
0.2
0.1
Distance from Golden Gate (km)
75
100
125
150
175
DSM2 Data
Middle River Salinity Gradient
Old River Salinity Gradient
San Joaquin River Salinity Gradient
Observed Data
Middle River
Old River
San Joaquin River

VII. Summary & Conclusions

This report presents two approaches for estimating the availability of water for in-Delta agricultural users south of the San Joaquin River. Both approaches assume that a “without project” hydrology is the appropriate baseline for measuring water availability for in-Delta water users located in the study area. This “without project” hydrology is a hypothetical hydrology that removes SWP-CVP upstream storage and in-Delta facility operations from the hydrologic record. As this hydrologic condition (and its associated water quality) cannot be measured in the field, both approaches rely on modeling frameworks as described in this report.

The first approach, an inflow criterion, assumes that when monthly Delta inflow approaches zero, no water is available for in-Delta agricultural use and curtailment of all water use in the study area is warranted. Furthermore, the criterion assumes that if monthly Delta outflow is positive, i.e. Delta inflow exceeds full in-Delta water use, water is available for all in-Delta use and no curtailment is warranted. This latter assumption ignores circumstances when Delta outflow is positive but sufficiently small such that seawater intrusion impairs the beneficial use of water in the study area, thereby limiting water availability for diversion.

The second approach, a salinity criterion, assumes that water is available for in-Delta agricultural use within the study area provided that water is of adequate quality to be put to beneficial use. As described in the report, the salinity criterion requires the use of hydrodynamic model simulations or mathematical representations of in-Delta flow-salinity relationships and specification of a salinity “trigger” to estimate water availability in the study area. Given that the low outflow conditions characteristic of the without project hydrology are outside the calibration range of the DSM2 model (which was used in the salinity criterion analysis), Delta salinity data collected in the 1920s and 1930s before construction of Shasta Dam were examined in detail. Two key conclusions were drawn from this data examination: (1) the study area was subject to severe seawater intrusion before construction and operation of the SWP-CVP and (2) the use of DSM2 and the DSM2-calibrated flow-salinity models allow for a reasonable and conservative method of evaluating water supply availability in the study area as part of the salinity criterion.

The inflow criterion analysis suggests that excess diversions are taking place in the study area, these diversions are centered in the April through August period, and the excess diversions are in the range of 300,000 acre-feet in dry and critical water years. The inflow criterion suggests that excess diversions take place in most years, but in smaller volumes under wetter hydrologic conditions.

The salinity criterion analysis also suggests that excess diversions are taking place in the study area. However, this analysis shows the diversions later in the season (typically June through November) with volumes in the range of 100,000 to 200,000 acre-feet in dry and critical water years. The salinity criterion suggests that excess diversions are of little consequence under wetter hydrologic conditions.

VIII. References

Denton, R.A. (1993). Accounting for Antecedent Conditions in Seawater Intrusion Modeling – Applications for the San Francisco Bay-Delta, Proceedings of the 1993 Hydraulic Division National Conference, American Society of Civil Engineers, San Francisco, Calif., H.W. Shen, Ed. 821-826.

DWR (2005). Testimony for SWRCB Hearing on Cease and Desist Order: Investigation of the Factors affecting Water Quality at Brandt Bridge, Middle River at Union Point, and Old River at Tracy, DWR Exhibit 20, Available online at: http://www.waterboards.ca.gov/waterrights/water_issues/programs/hearings/delta_salinity/exhibits/dwr/dwr20.pdf

DWR (2012a). DAYFLOW Database, Available online at: http://www.water.ca.gov/dayflow/

DWR (2012b). California Data Exchange Center (CDEC), Available online at: http://cdec.water.ca.gov/

DWR (2014). The State Water Project Final Delivery Reliability Report 2013, December, Available online at: http://baydeltaoffice.water.ca.gov/swpreliability/

DWR and USBR (1958). 1957 Joint Hydrology Study: Sacramento River and Sacramento-San Joaquin Delta, July.

Harder, J.A. (1977). Predicting Estuarine Salinity from River Inflows, Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, Vol. 103, No. HY8, August, pp. 877-888.

Hutton, P. (2014). Delta Salinity Gradient (DSG) Model, Version 1.0 Model Documentation, Metropolitan Water District of Southern California, Technical Memorandum, September.

Hutton, P.H., Rath, J., Chen, L., Ungs, M.J. and Roy, S.B. (2015). Nine Decades of Salinity Observations in the San Francisco Bay and Delta: Modeling and Trend Evaluation, Journal of Water Resources Planning and Management, ASCE, manuscript submitted for publication, March.

Tetra Tech, Inc. (2014). Salinity Trends in Suisun Bay and the Western Delta: October 1921 – September 2012, Prepared for San Luis and Delta Mendota Water Authority and State Water Contractors, January 16.

Tetra Tech, Inc. (2015a). Technical Analysis in Support of South Delta Diversion Curtailment in Dry Years, Prepared for Metropolitan Water District of Southern California, May.

Tetra Tech, Inc. (2015b). Mapping and Trend Evaluation of Interior Delta Salinity, Prepared for Metropolitan Water District of Southern California, March.

Water and Power Resources Service (USBR) and South Delta Water Agency (SDWA) (1980). Effects of the CVP upon the Southern Delta Water Supply: Sacramento – San Joaquin Delta, California, June.

IX. Appendix A: Methodology to Estimate Vernalis Salinity Under Without Project Conditions (from USBR & SDWA 1980)

This appendix presents a methodology to estimate salinity at the San Joaquin River at Vernalis in units of specific conductance (mS/cm). The methodology was developed in the report “Effects of the CVP upon the Southern Delta Water Supply: Sacramento – San Joaquin Delta, California” (USBR & SDWA 1980).

A. Calculate Salt Load Based on Flow (Table VI-7, page 89)

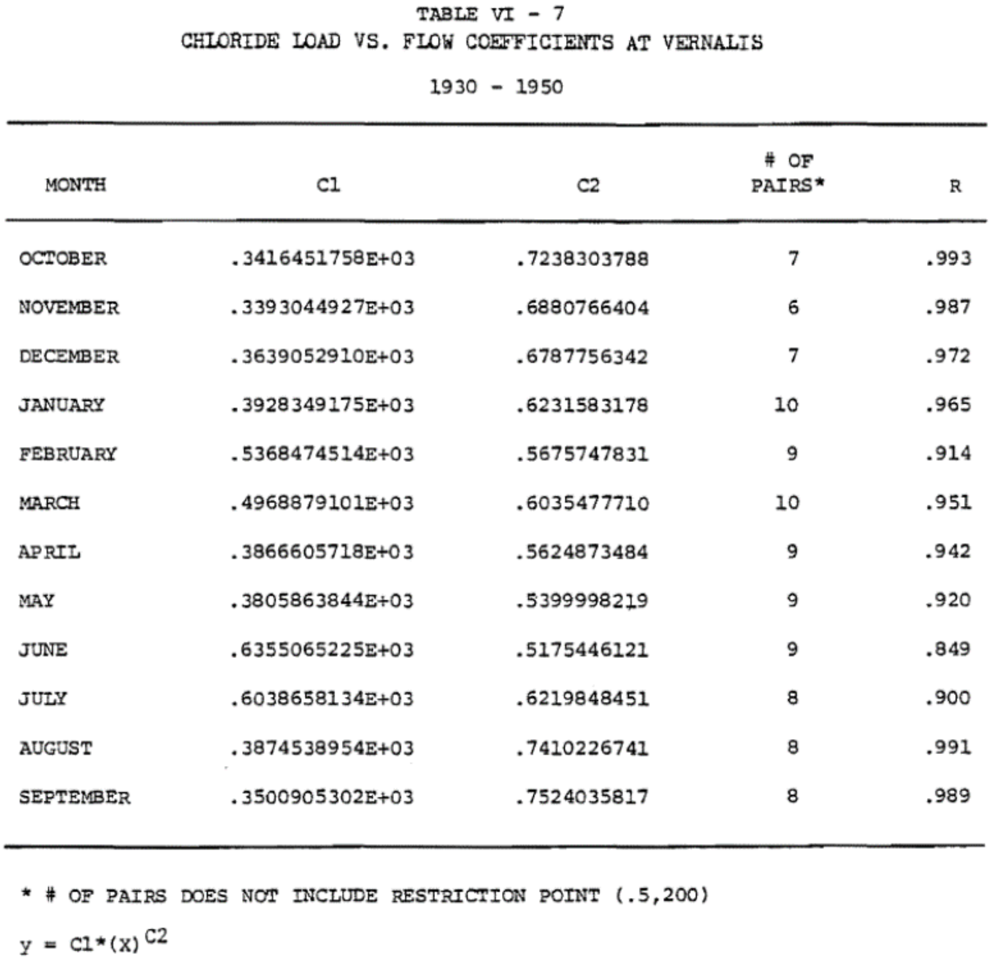


TABLE VI - 7
CHLORIDE LOAD VS. FLOW COEFFICIENTS AT VERNALIS
1930 - 1950

MONTH	C1	C2	# OF PAIRS*	R
OCTOBER	.3416451758E+03	.7238303788	7	.993
NOVEMBER	.3393044927E+03	.6880766404	6	.987
DECEMBER	.3639052910E+03	.6787756342	7	.972
JANUARY	.3928349175E+03	.6231583178	10	.965
FEBRUARY	.5368474514E+03	.5675747831	9	.914
MARCH	.4968879101E+03	.6035477710	10	.951
APRIL	.3866605718E+03	.5624873484	9	.942
MAY	.3805863844E+03	.5399998219	9	.920
JUNE	.6355065225E+03	.5175446121	9	.849
JULY	.6038658134E+03	.6219848451	8	.900
AUGUST	.3874538954E+03	.7410226741	8	.991
SEPTEMBER	.3500905302E+03	.7524035817	8	.989

* # OF PAIRS DOES NOT INCLUDE RESTRICTION POINT (.5,200)

$y = C1*(X)^{C2}$

B. Convert Salt Load to Chloride Concentration (page 110)

$$p/m = \frac{\text{Load}}{\text{Flow} \times 1.36}$$

where,

p/m = parts per million Cl^-
Load = chloride load in tons
Flow = 1,000's of acre-feet

C. Calculate Specific Conductance EC from Chloride Concentration (page 86)

$$Cl^- = 0.15\ EC - 5.0 \qquad (2a)$$
$$0 < EC < 500$$

$$Cl^- = 0.202\ EC - 31.0 \qquad (2b)$$
$$500 < EC < 2000$$

Rearranging the equations to solve for EC yields:

EC = (Cl- + 5.0) / 0.15 0 < EC < 500

EC = (Cl- + 31.0) / 0.202 500 < EC < 2000

X. Appendix B: DSM2 Salinity Frequency Charts

The charts provided in this appendix compare salinity exceedance probabilities associated with two DSM2 scenarios: an existing conditions scenario (blue line) and a without project conditions scenario (red line). Charts are provided for every month at three locations in the study area: Old River at Bacon Island (ROLD024), San Joaquin River at Stockton (RSAN063), and Grant Line Canal at Tracy Road Bridge. Salinity data are in units of uS/cm (mS/cm x 1000) and are monthly averaged and shown on a log scale in the charts. A simple interpretation of the charts is as follows: (1) a 0.2 exceedance probability means that the salinity is higher than that value 20% of the time and lower than that value 80% of the time, (b) periods when the red line is above the blue line are indicative of periods when SWP-CVP operations improve water quality conditions, and (c) periods when the blue line is above the red line are indicative of periods when SWP-CVP operations degrade water quality conditions.

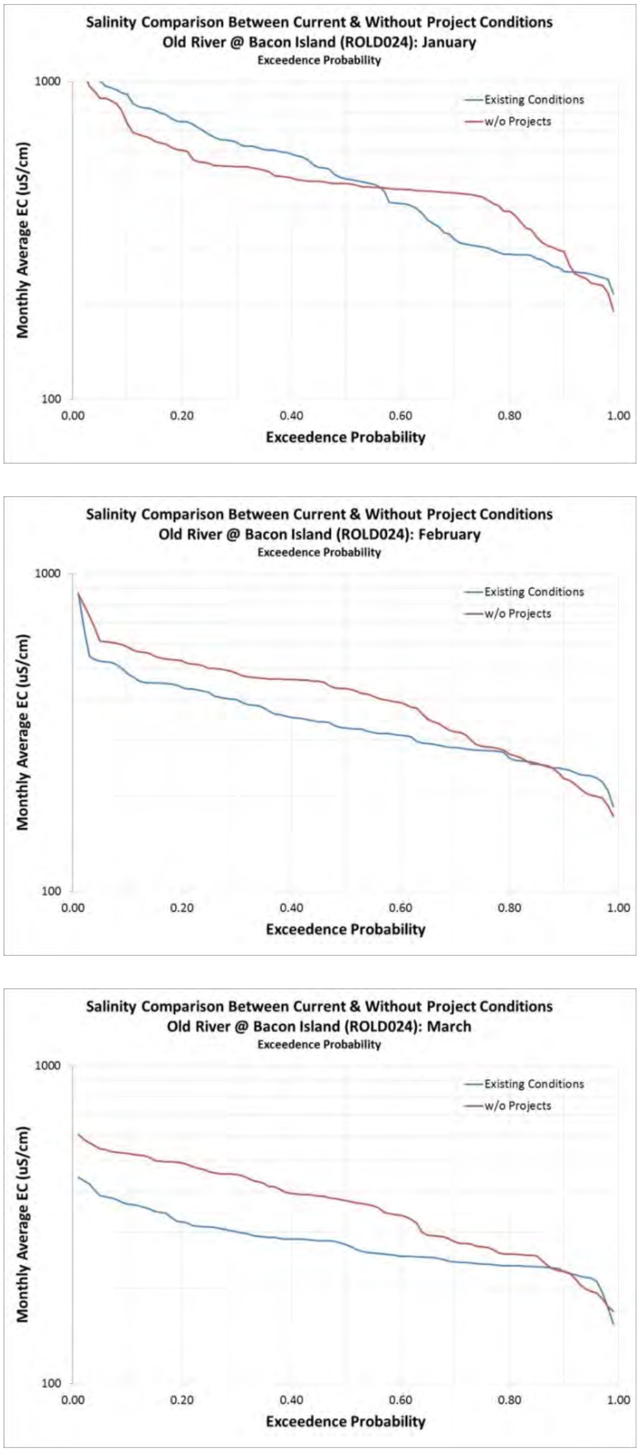
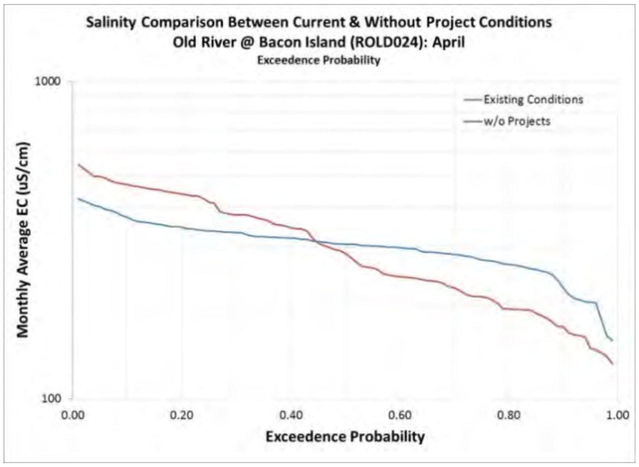
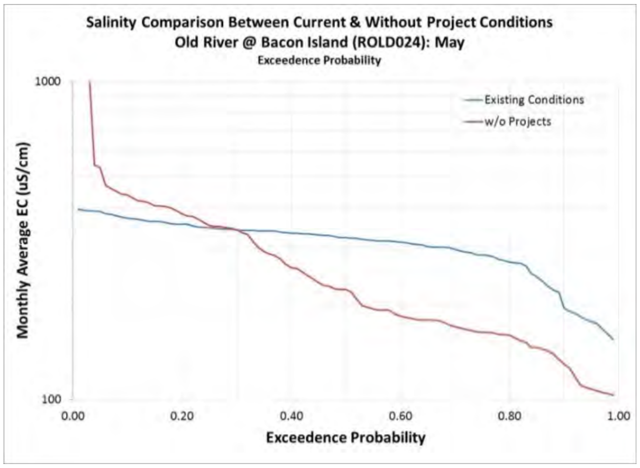


Figure B.1 Salinity Comparison between Current & Without Projects Scenarios: Old River @ Bacon Island (ROLD024); January, February & March





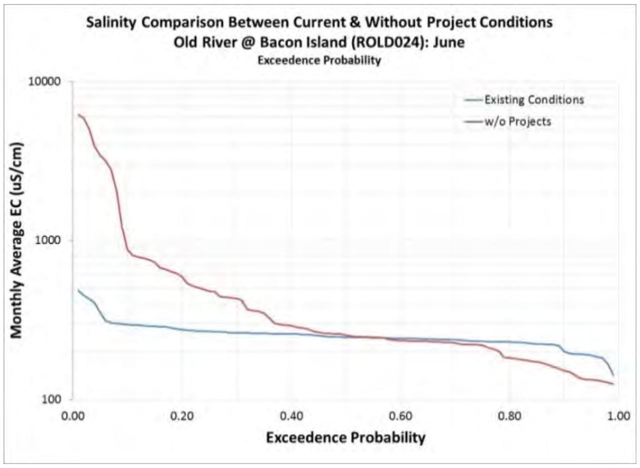
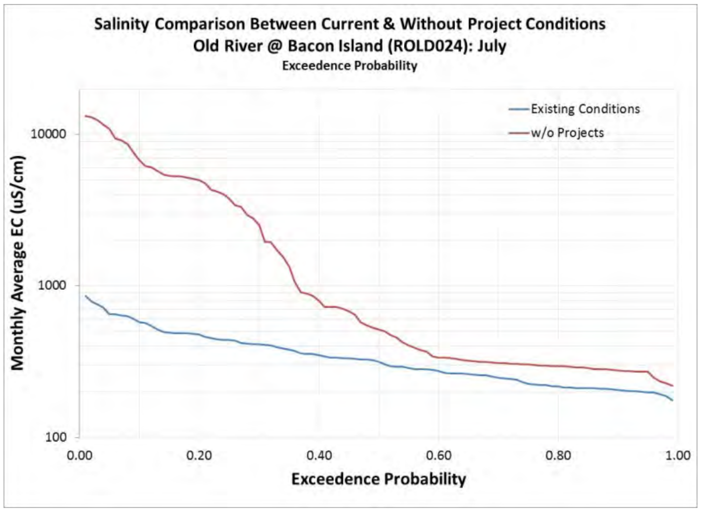
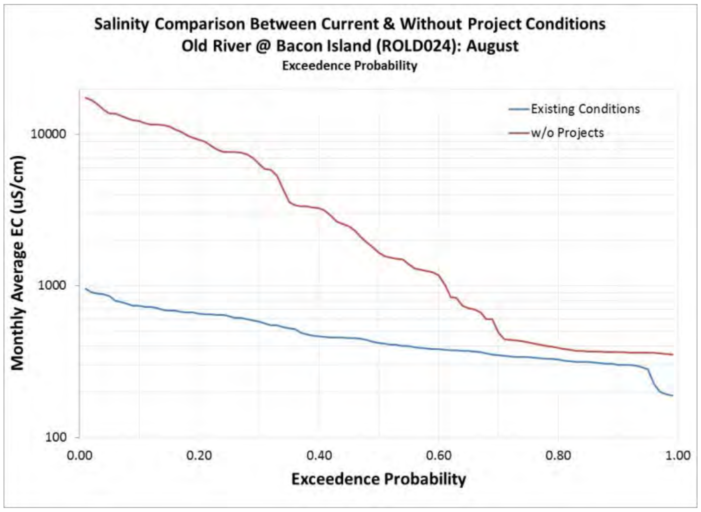


Figure B.2 Salinity Comparison between Current & Without Projects Scenarios: Old River @ Bacon Island (ROLD024); April, May & June





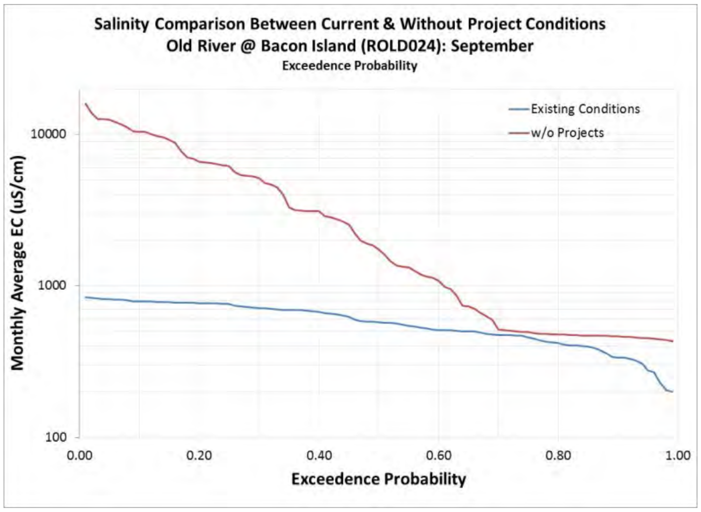
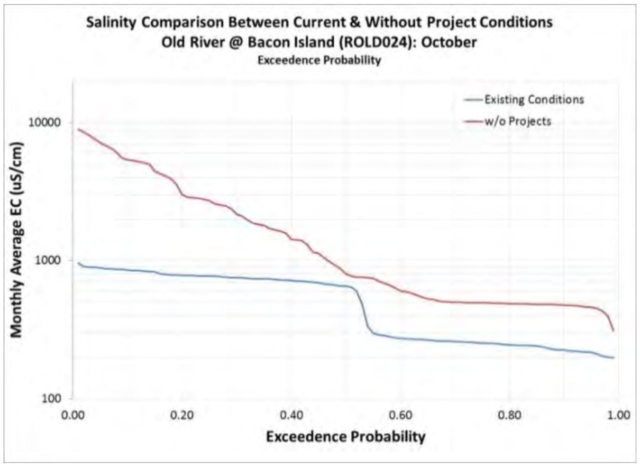
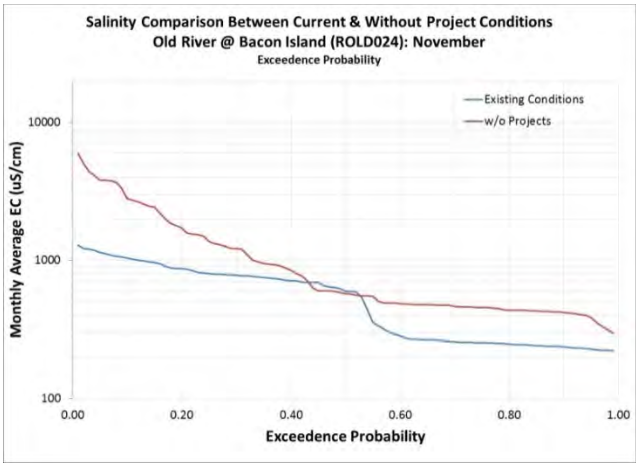


Figure B.3 Salinity Comparison Between Current & Without Projects Scenarios: Old River @ Bacon Island (ROLD024); July, August & September





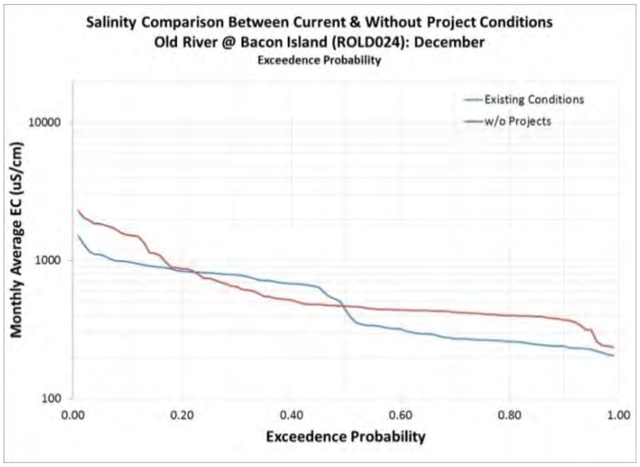
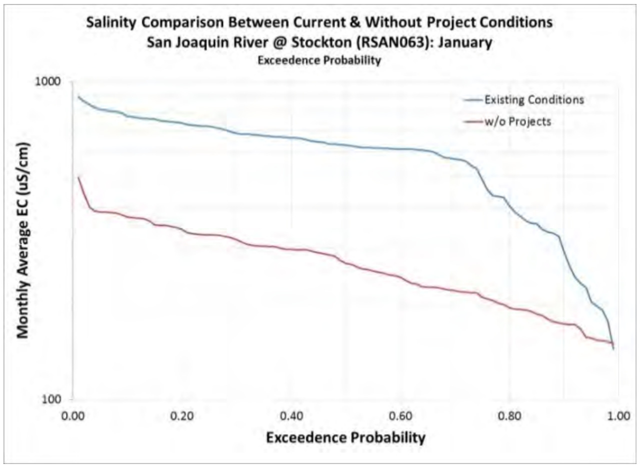
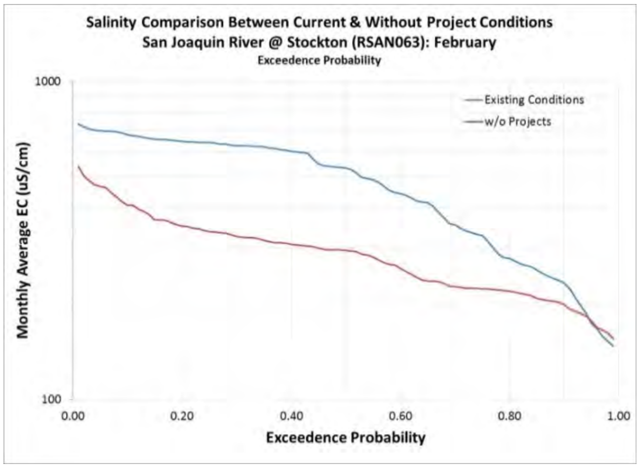


Figure B.4 Salinity Comparison Between Current & Without Projects Scenarios: Old River @ Bacon Island (ROLD024); October, November & December





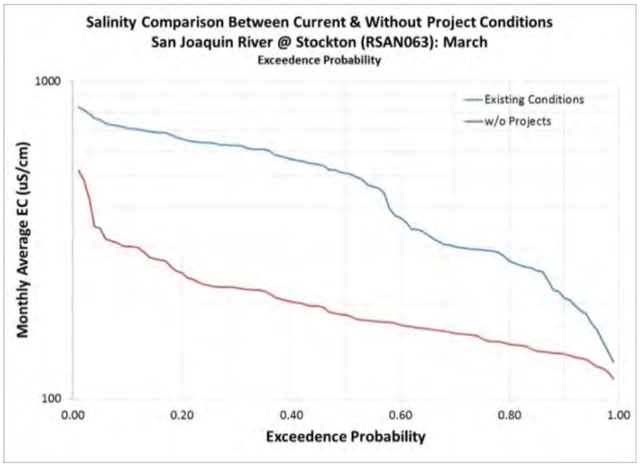
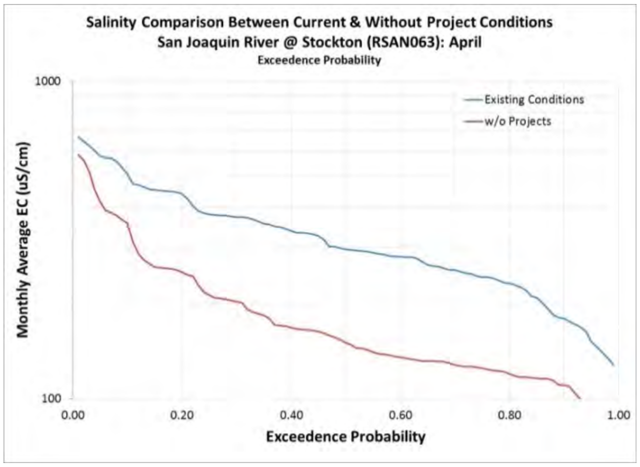
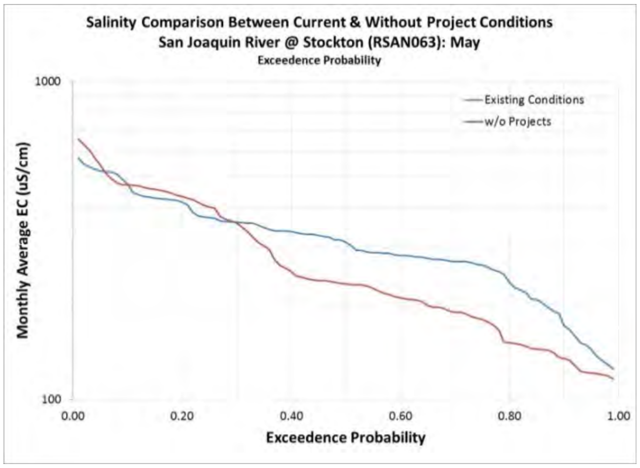


Figure B.5 Salinity Comparison Between Current & Without Projects Scenarios: San Joaquin River @ Stockton (RSAN063); January, February & March





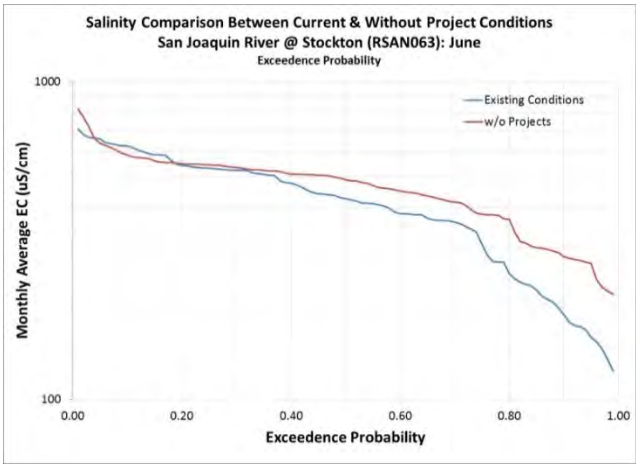
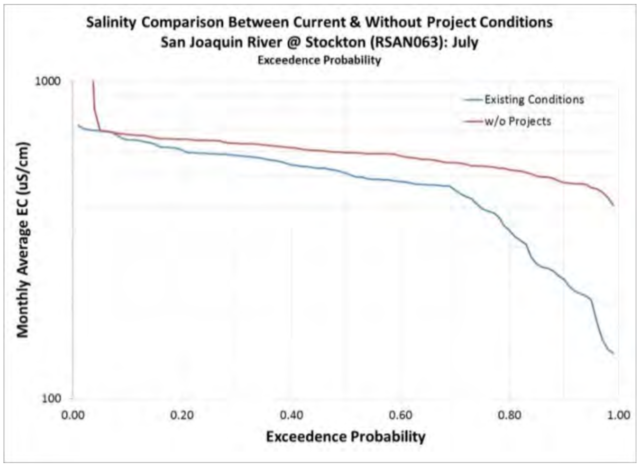
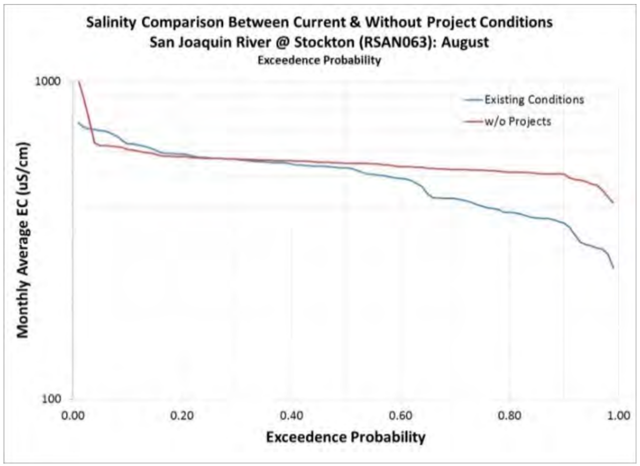


Figure B.6 Salinity Comparison Between Current & Without Projects Scenarios: San Joaquin River @ Stockton (RSAN063); April, May & June





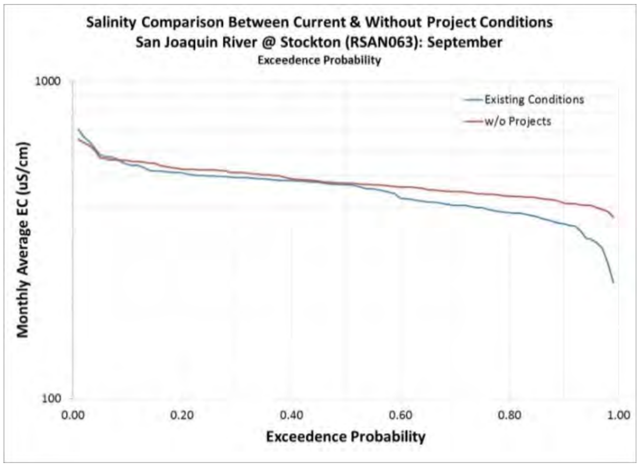
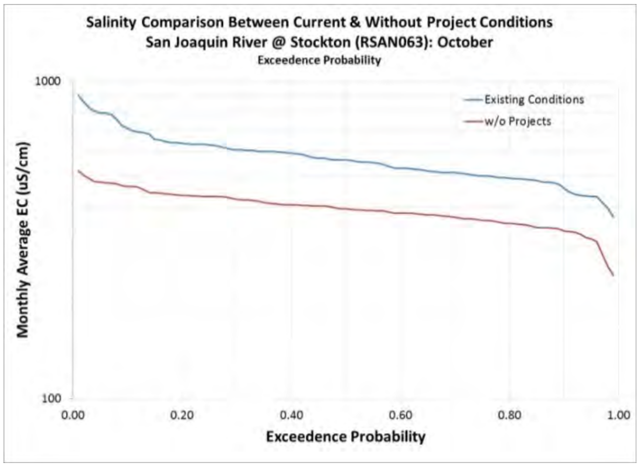
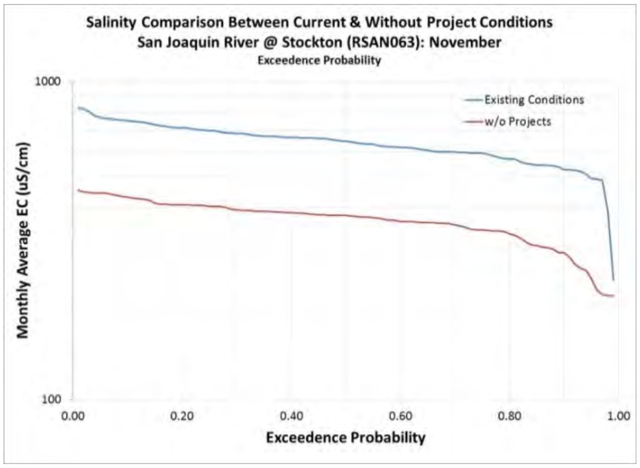


Figure B.7 Salinity Comparison Between Current & Without Projects Scenarios: San Joaquin River @ Stockton (RSAN063); July, August & September





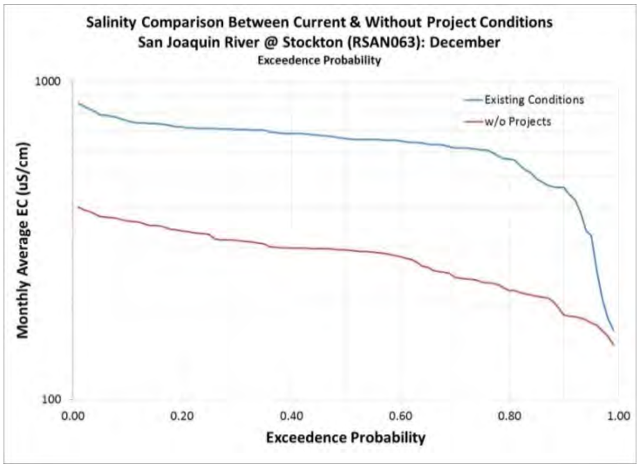
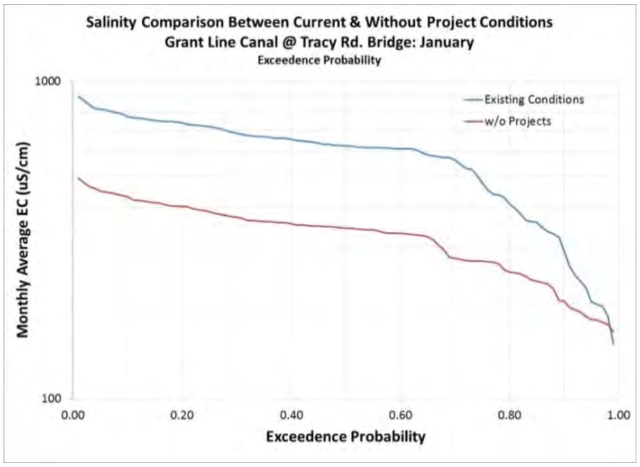
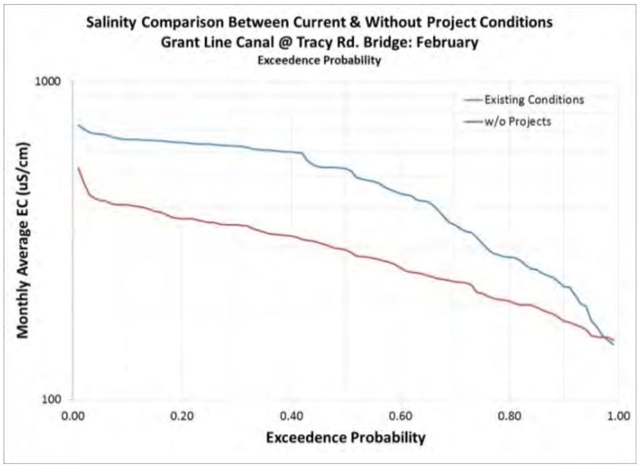


Figure B.8 Salinity Comparison Between Current & Without Projects Scenarios: San Joaquin River @ Stockton (RSAN063); October, November & December





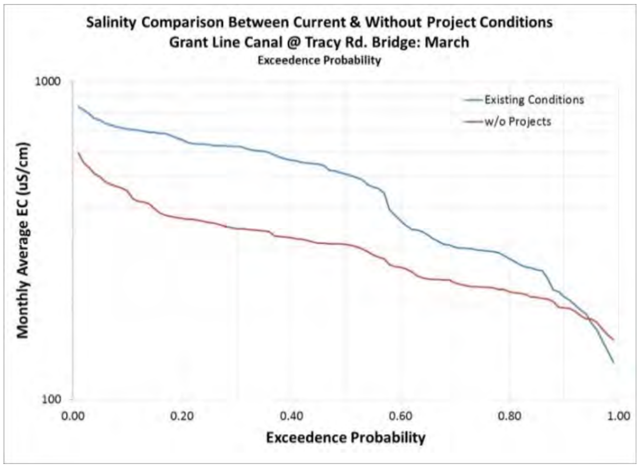
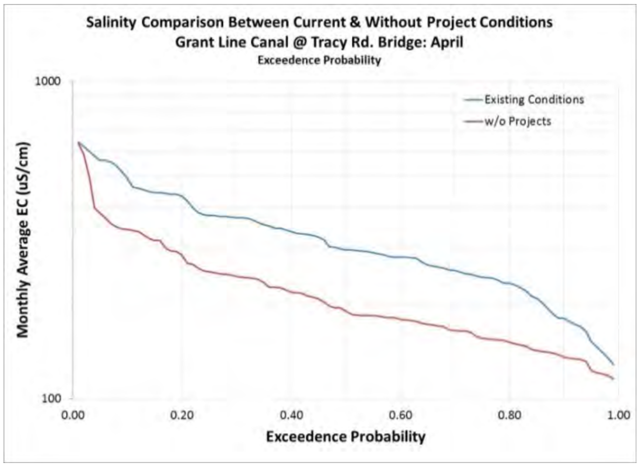
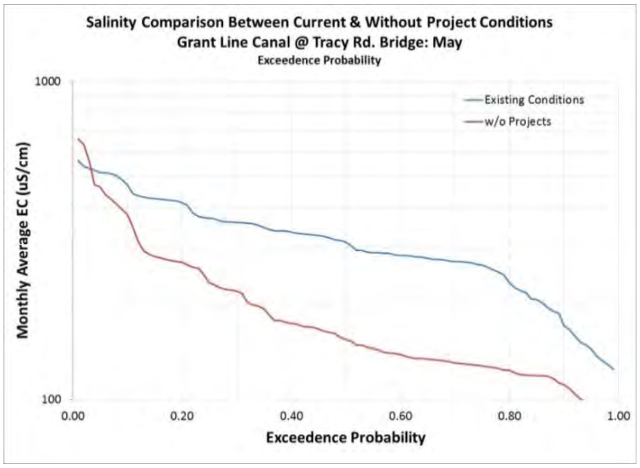


Figure B.9 Salinity Comparison Between Current & Without Projects Scenarios: Grant Line Canal at Tracy Road Bridge; January, February & March





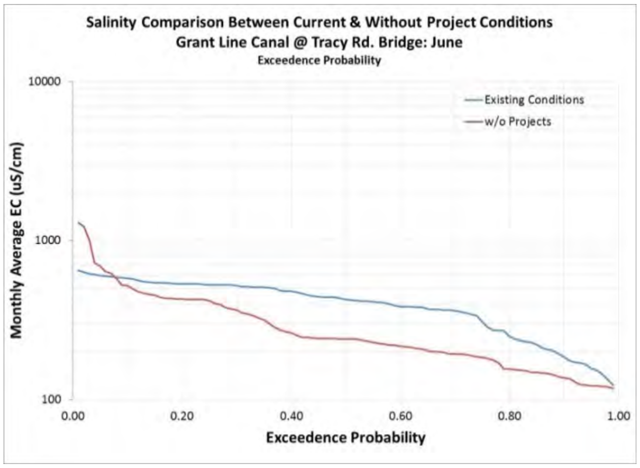
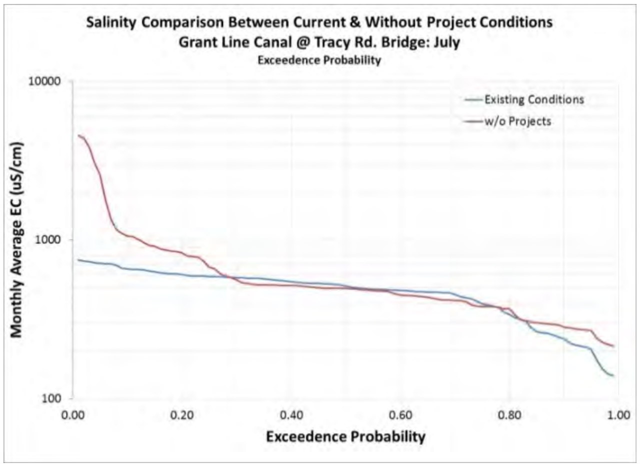
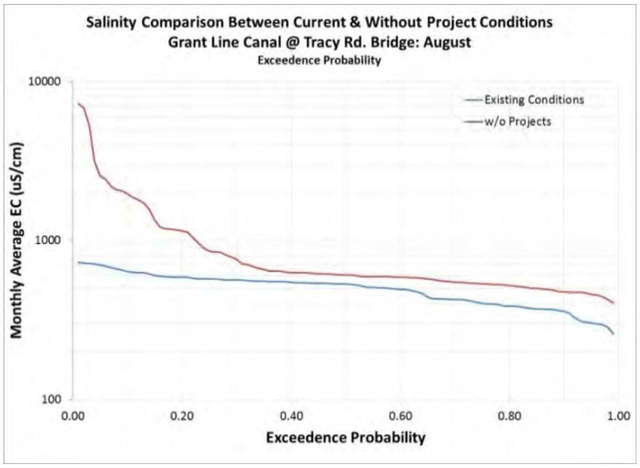


Figure B.10 Salinity Comparison Between Current & Without Projects Scenarios: Grant Line Canal at Tracy Road Bridge; April, May & June





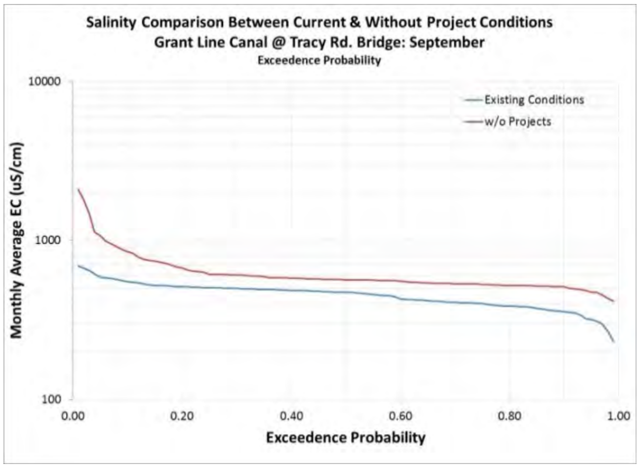
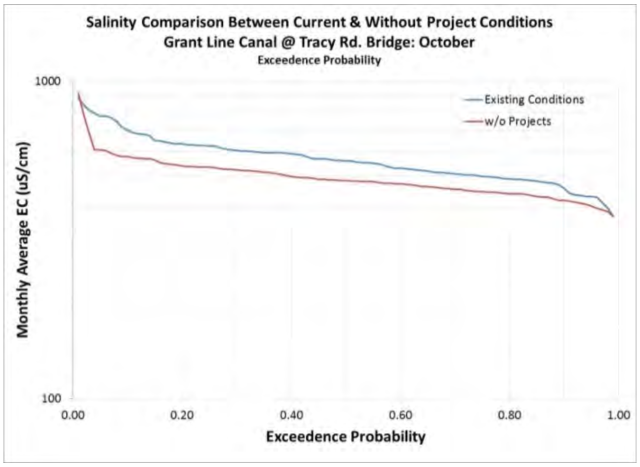
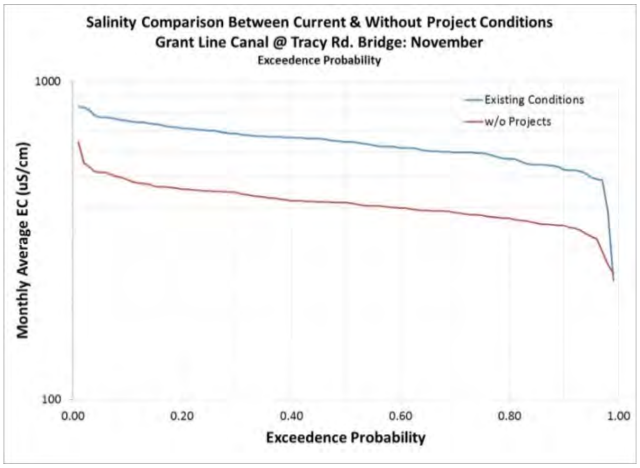


Figure B.11 Salinity Comparison Between Current & Without Projects Scenarios: Grant Line Canal at Tracy Road Bridge; July, August & September





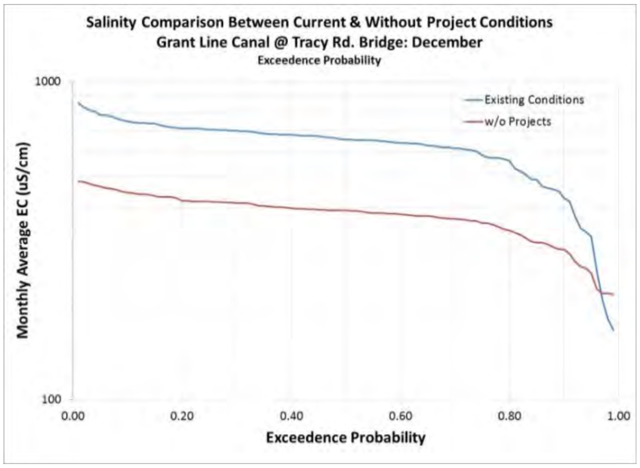


Figure B.12 Salinity Comparison Between Current & Without Projects Scenarios: Grant Line Canal at Tracy Road Bridge; October, November & December

Appendix C: Study Area Channel Distance – Area Lookup Tables

Relationships between channel distance and cumulative downstream area were developed for the three river reaches – Old, Middle and San Joaquin – within the study area (Tetra Tech 2015a). Such relationships provide a method to estimate the location and total area downstream of a prescribed salinity trigger, i.e. the curtailment area. These relationships are provided as lookup tables (Tables C.1, C.2 and C.3) in this appendix. Thus, by defining a salinity trigger, the downstream curtailment area can be calculated for any hydrologic condition defined by the antecedent outflow G.

DSM2 Node No.	Distance from Golden Gate (km)	Cumulative Area (acres)	DSM2 Node No.	Distance from Golden Gate (km)	Cumulative Area (acres)
45	94.0	0	21	136.9	27460
469	97.9	2166	20	138.0	28153
44	99.8	3066	19	139.3	28153
43	102.3	3140	18	140.4	28157
42	105.8	4758	16	141.8	29896
41	108.8	5683	15	143.2	30018
40	112.0	5802	14	144.3	30736
39	113.6	6257	13	145.3	31170
38	114.5	6400	12	148.7	34307
37	117.0	6400	11	151.5	36573
35	118.5	6411	10	153.7	38453
34	120.0	6411	9	156.1	39316
33	122.2	6534	8	158.4	39664
32	122.9	6713	7	160.5	39947
30	124.9	8542	6	162.6	41542
29	127.0	11212	5	165.2	46789
26	128.9	13437	4	168.4	58958
25	130.1	17114	3	170.7	62019
24	131.3	19868	2	171.9	65712
23	133.0	23503	1	175.1	70536
22	134.8	25924	17	177.3	72761

Table C.1 San Joaquin River Distance-Area Lookup Table

DSM2 Node No.	Distance from Golden Gate (km)	Cumulative Area (acres)
38	114.5	0
103	116.6	927
101	118.6	1649
100	121.6	2423
98	122.5	3002
97	124.1	3308
97	125.2	3614
94	126.8	4586
93	127.7	6642
92	128.9	7124
91	129.8	7455
90	130.7	11535
89	131.8	11901
88	132.5	12509
86	133.7	12699
85	134.4	13312
84	135.4	13960
82	136.5	15130
81	138.0	18269
80	139.2	19749
79	140.3	23254
78	142.2	28466
77	143.0	29462
75	144.4	29632
192	145.4	31079
187	146.0	31432
185	147.1	32264
183	147.7	35143
182	149.0	36257
72	150.1	36452
71	150.8	36685
70	151.5	38696
69	152.6	39885
68	153.9	40856
67	155.3	41819
66	156.5	43448
65	158.1	46482
64	159.2	48720
63	160.2	49684
62	161.3	50676
61	162.2	53684
60	163.9	54455
59	164.7	58363
57	166.3	58747
56	167.0	61133
55	168.1	63407
54	169.7	66222
53	170.7	66681
52	171.6	66934
51	173.1	68215
50	174.1	68898
49	174.8	69471
48	175.9	71657
8	176.8	72005

Table C.2 Old River Distance-Area Lookup Table

DSM2 Node No.	Distance from Golden Gate (km)	Cumulative Area (acres)
35	118.5	0
134	119.9	425
133	122.5	849
132	123.7	1083
130	124.8	2527
129	125.6	2656
128	126.2	2905
127	127.1	3433
126	128.3	4212
125	129.5	4558
124	130.5	6920
122	132.1	7326
121	132.7	7997
120	133.7	9000
119	134.7	9483
118	136.1	11505
117	136.7	12226
116	137.9	13501
115	138.9	16208
114	139.9	17192
113	140.7	18943
112	142.7	22210
111	144.2	24891
110	146.0	29094
108	147.7	32089
109	149.8	34926
107	151.6	36954
106	153.3	38884
105	155.2	40701
104	156.8	41634
52	157.7	41887

Table C.3 Middle River Distance-Area Lookup Table

Attachment 4

Technical Analysis in Support of South Delta Diversion Curtailment in Dry Years
Final Report

Prepared for:

State Water Contractors
1121 L. Street, Suite 1050, Sacramento, CA 95814

Technical Representative:

Paul Hutton, Ph.D., P.E.
Metropolitan Water District of Southern California
1121 L Street, Suite 900, Sacramento CA 95814-3974

Prepared by:

TETRA TECH

3746 Mt. Diablo Blvd., Suite 300
Lafayette, CA 94549
USA

June 3, 2015

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The Sacramento – San Joaquin Delta is a source of water supply for water users located in the Delta and for the users south-of-Delta. The Delta receives flow primarily from the Sacramento and San Joaquin Rivers, as well as from other smaller rivers such as the Mokelumne, Cosumnes and Calaveras on the eastside of the Delta (Eastside Streams), as well as tidal flow from San Francisco Bay. Delta inflow from the Sacramento and San Joaquin Rivers are partially a result of the stored water releases from the upstream reservoirs operated by the Central Valley Project (CVP) and State Water Project (SWP). The water released from these reservoirs is diverted from the Delta for the water supply needs of the south-of-Delta CVP and SWP contractors, in addition to meeting the existing regulatory requirements. This study examined the contribution of Sacramento and San Joaquin River flows to water users in the Delta under current conditions, as well as conditions that were simulated to represent freshwater inflows that would occur in the absence of the projects.

The primary tool used for this work was the California Department of Water Resources' DSM2 model. The model was run for different inflow scenarios and the resulting simulation of volumetric contributions of flow and salinity were used to describe behavior under project and without project conditions. The following inflow scenarios were used to simulate 82-year (water years 1922-2003) Delta hydrodynamics, electrical conductivity (EC) and volumetric fingerprinting using DSM2 for the following four scenarios:

Scenario A: Current conditions with hydrology based on the DWR's 2013 Delivery Reliability Report (DRR)

Scenario B: Scenario A without in-Delta agricultural diversions

Scenario C2[1]: "Without Project" conditions. This hydrology development removed the impairment caused by the upstream CVP and SWP reservoirs on the Sacramento

---

[1] This was originally referred to as Scenario C, but was relabeled to C2 after a different EC boundary condition was utilized, as described in the following chapter.

and San Joaquin Rivers, and the CVP and SWP diversions in the Delta. Using impaired and unimpaired flow time series information downstream of the following SWP/CVP reservoirs, we estimate changes to flow volumes from the following reservoirs: Oroville, Friant (Millerton), New Melones, Shasta (and Trinity River inflows), and Folsom. The changes to flows downstream of the reservoir locations (increase or decrease, depending on month and year) were represented as changes to stream flows at the following locations: Sacramento River at Freeport, Yolo Bypass, and San Joaquin River at Vernalis. The Without Project hydrology was estimated on a monthly basis. The Without Project scenario excludes south Delta CVP-SWP export facilities, the Delta Cross Channel (DCC), south Delta temporary barriers and Montezuma Salinity Control Gate. It includes Contra Costa Water District (CCWD) and North Bay Aqueduct (NBA) diversions, and the BBID diversion was moved to the Old River.

Scenario D: Scenario C2 without in-Delta agricultural diversions. This scenario also excludes NBA and CCWD diversions.

Scenario E: Flows assuming actual (DAYFLOW) hydrology from water year 1922-1944.

The following chapters describe the DSM2 runs utilized, the development of a simplified modeling framework using DSM2 output, i.e., a Delta Salinity Gradient model applied to channels in the South Delta, the validation of the DSM2 output data using South Delta observed salinity from the pre-Project period, and the development of a relationship between irrigated area and distance from Golden Gate Bridge along the major river channels in the South Delta. Because the DSM2 results are voluminous, this memorandum is accompanied by electronic results for flow, EC, and volumetric fingerprint values, and only a few key aspects of the output are highlighted in the document and appendices.

2. DSM2 ANALYSIS

The DSM2 analysis used input files developed by DWR to represent current conditions (i.e., the existence of projects, reservoir operations, and exports from the Delta) driven by an 82-year hydrology representing WY 1922-2003. Thus, Scenario A, as defined in Chapter 1 was based on DWR inputs, and these inputs were modified to represent other scenarios. The most important changes related to the development of the without project hydrology boundary and the without project EC boundary condition at Vernalis on the San Joaquin River that are described below.

2.1 WITHOUT PROJECT HYDROLOGY BOUNDARY

The "Without Project" Delta hydrology boundary conditions were used to represent the conditions without the CVP and the SWP project. The Without Project hydrology removed the impairment caused by upstream CVP and SWP reservoirs and CVP and SWP diversions in the Delta but maintained impairments caused by upstream agricultural and municipal project diversions.

The Without Project boundary was developed by modifying the Delta inflow using the difference between inflow and releases for the upstream reservoirs operated by CVP and SWP simulated by CALSIM II.[2] The inflow to the Delta from Sacramento River and Yolo Bypass was modified by the difference between inflow and releases to the Oroville, Shasta and Folsom reservoirs. For the Without Project scenario, the inflow from Trinity River was also subtracted. The total of Sacramento River and Yolo Bypass flow from CALSIM II current conditions represents the original flow from the Sacramento Valley to the Delta. It was then modified by the difference between the release and inflow to the three reservoirs, and minus inflow from the Trinity River to obtain the Without project flow, as follows:

$$\text{SAC\_mod} = C169 + C157 + (I4 + I6 + I300) - (C4 + C6 + C8) - I1 \qquad (1)$$

Each component as defined in CALSIM II for the current conditions is:
C169: Sacramento River flow

---

[2] This information was obtained from previous DWR work.

C157: Yolo Bypass flow
I4: Sacramento River Inflow to Shasta Lake
I6: Feather River Inflow to Lake Oroville
I300: American River upstream Inflow to Folsom
C4: Release from Shasta Lake
C6: Feather River downstream of Oroville
C8: American River below Folsom Dam
I1: Trinity River Inflow

The calculated modified inflow from the Sacramento Valley was then split into Sacramento River flow and Yolo Bypass flow based on the operation rules from CALSIM II. The gate from Sacramento River to Yolo is assumed to open at a flow of 21,000 cfs. The maximum flow in the Sacramento River is assumed to be 62,000 cfs. Flows above 62,000 cfs are assumed to spill into Yolo Bypass. This is based on existing CALSIM operating rules for the bypass. The estimated Without Project flow at Sacramento River and Yolo Bypass, compared to current conditions from CALSIM II is shown in Figure 1 and Figure 2. Inflows at Freeport were set to zero when the calculated inflows resulted in negative values.

The San Joaquin River inflow for the Without Project boundary was developed by modifying the inflow from Vernalis and the difference between releases and inflow to the New Melones and Millerton (Friant) Reservoirs. For the Without Project boundary (for the C2 scenario), both the New Melones and Millerton Reservoirs were unimpaired. The return flow from the Exchange Contractor flows into San Joaquin River at Salt Slough and Merced.

The equation used to calculate modified inflow from the San Joaquin River for the C2 scenario (SJR_modc2) is:

$$\text{SJR\_modc2} = \text{C639} + (\text{I10}-\text{C10}) + (\text{I18}-\text{C18}) + \text{R614J} + \text{R619H} - \text{D607B\_Mod} - 400\text{ cfs} \tag{2}$$

Where,
C639: San Joaquin River below Vernalis
I10: Inflow to New Melones
I18: inflow to Millerton
C10: Release from New Melones
C18: Release from Millerton
D607B: Mendota pool/Exchange DIV
D607B_mod: Mendota pool/Exchange DIV capped using SJR flow below Mendota Pool (C607) C607: SJR below Mendota Pool
R614j: pool exchange contractors return flows to SJR at Salt Slough
R619h: pool exchange contractors return flows to SJR at Merced

The assumed 400 cfs term is groundwater loss from the San Joaquin River channel. When the above equation resulted in negative flows, a minimum flow of 150 cfs was used. When using the minimum flow of 150 cfs, DSM2 occasionally resulted in dry channels. When this occurred, a higher flow of 300 cfs was used. The estimated Without Project flow at San Joaquin River at Vernalis, compared to current conditions from CALSIM II is shown in Figure 3.

2.2 EC AT SAN JOAQUIN RIVER

For the EC boundary conditions at Vernalis, the equations documented in a previous analysis by the Water and Power Resources Service and the South Delta Water Agency were used.[3] The approach first calculated salt load based on the San Joaquin River flow (Figure 4). The estimated salt load was then converted to concentrations of chloride (Cl). The salt load was converted to concentrations based on equations on page 110 in the Water and Power Resources Service and the South Delta Water Agency (1980) report:

$p/m = \text{Load} / (\text{flow} \times 1.36)$ (3)
where,
p/m = parts per million Cl^-
load = chloride load in tons
flow = 1000’s of acre-feet

The calculated Cl- concentrations were then converted to EC using the following equations (page 86 in 1980 report):

$Cl^- = 0.15EC - 5.0$ $0 < EC < 500$ (4)
$Cl^- = 0.202EC - 31.0$ $500 < EC < 2000$ (5)
Then:
$EC = (Cl^- + 5.0) / 0.15$ $0 < EC < 500$ (6)
$EC = (Cl^- + 31.0) / 0.202$ $500 < EC < 2000$ (7)

Estimated EC at the Vernalis boundary is shown in Figure 5.

2.3 DSM2 RUNS FOR SCENARIOS A, C2, D, AND E

The DSM2 model, version 8.0.6, was run for the 82-year hydrology using the planning mode. The tide file used is the 82-year planning tide records at Martinez (planning-2-SL). The gate file used is the 82-year planning gate at Clifton Court. The operation rules used

---

[3] Effects of the CVP upon the Southern Delta Water Supply, Sacramento-San Joaquin River Delta, California, prepared jointly by the Water and Power Resources Service and the South Delta Water Agency, June 1980; Scanned copy available online at:
http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/docs/cmnt081712/cwin/cwinappendix_f.pdf

for Montezuma Slough and South Delta temporary barriers are the planning rules for these locations.

Scenario E is run using DAYFLOW records as the hydrological boundary, including the Sacramento River at Freeport, San Joaquin River near Vernalis, Yolo Bypass, Mokelumne, Calaveras, and Cosumnes River for the time period of 1922-1944. For Scenario E, the tide at Martinez was developed by subtracting 0.55 ft from the current 82-year planning tide, based on the difference between the baseline and 1920's sea level at Golden Gate, in order to represent tide levels in the 1920s.

The model simulated EC concentrations for the A and C2 scenarios are shown for illustration at two locations in Figure 6 and Figure 7. Model results for all scenarios are provided electronically.

2.4 COMPARISON OF VOLUMETRIC FINGERPRINTS ACROSS SELECTED STATIONS IN THE SOUTH DELTA FOR SCENARIOS C2 AND D

In this section, we compare model simulated percent volumetric contribution from source waters from two scenarios: scenario C2 and D, at 14 locations listed in Table 1. Simulated volumetric contributions from four major source waters were compared: Ag (agricultural /DICU flow), East (eastside streams), Sac (Sacramento River at Freeport), and SJR (San Joaquin River flow at Vernalis). The comparisons were made for each month from January to December. For each station, a total of 12 plots (representing January to December) were created (Appendix A).

The comparison of Scenarios C2 and D showed the effects of DICU flow on simulated volumetric contributions on monthly basis. The results suggest that without DICU flow, SJR contribution is 100% at many locations. With the contribution from DICU flow (Scenario C2), SJR flow contribution is lower. The contribution of DICU flow at some Delta locations appears to be significant.

The relationship between the San Joaquin River flow and the percent volumetric contribution from the Sacramento River was also evaluated for the 14 stations (individual plots not shown). The results generally suggested a negative relationship between volumetric contribution from the Sacramento River and San Joaquin River flow. The contribution from the Sacramento River decreased exponentially with San Joaquin River flow and is only evident at very low San Joaquin River flow. For locations proximal to the head of the rivers (e.g., Old River) the contribution from the Sacramento River is minimal.

Table 1
Selected output locations in the south Delta

Station	Name
Old River @ Holland	Rold014
Old River @ Bacon Island	Rold024
Old River @ Hwy 4	Rold034
Just outside of CCF intake	chswp003
Old River @ Tracy Rd Bridge	Rold059
Old River @ Union Island (Old R @ Middle R)	oldr_midr
Old River @ Head	Rold074
Grant Line Canal @ Tracy Rd Bridge	CHGRL009
Middle River @ Holt	Rmid005
Middle River @ Bacon Island	Rmid015
Middle River @ Victoria Canal	Rmid027
SJR @ Turner Cut	RSAN046
SJR @ Stockton	RSAN063
SJR @ Brandt Bridge	RSAN072

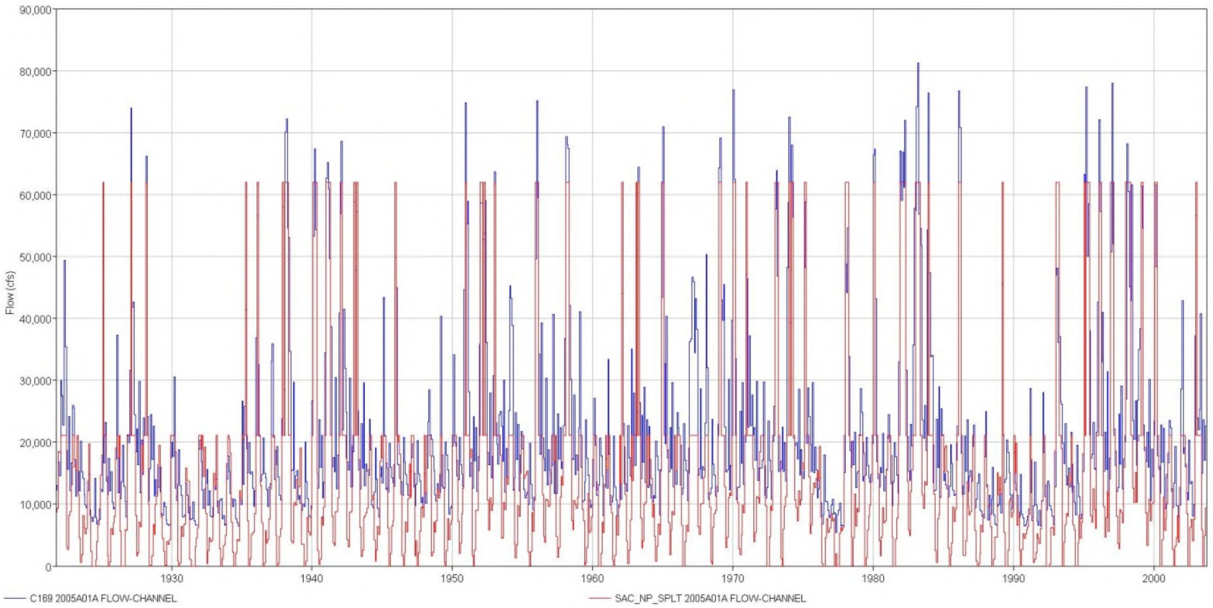


Figure 1 Comparison of Sacramento River inflow to the Delta for the current conditions (blue) and the Without Project C2 scenario (red)

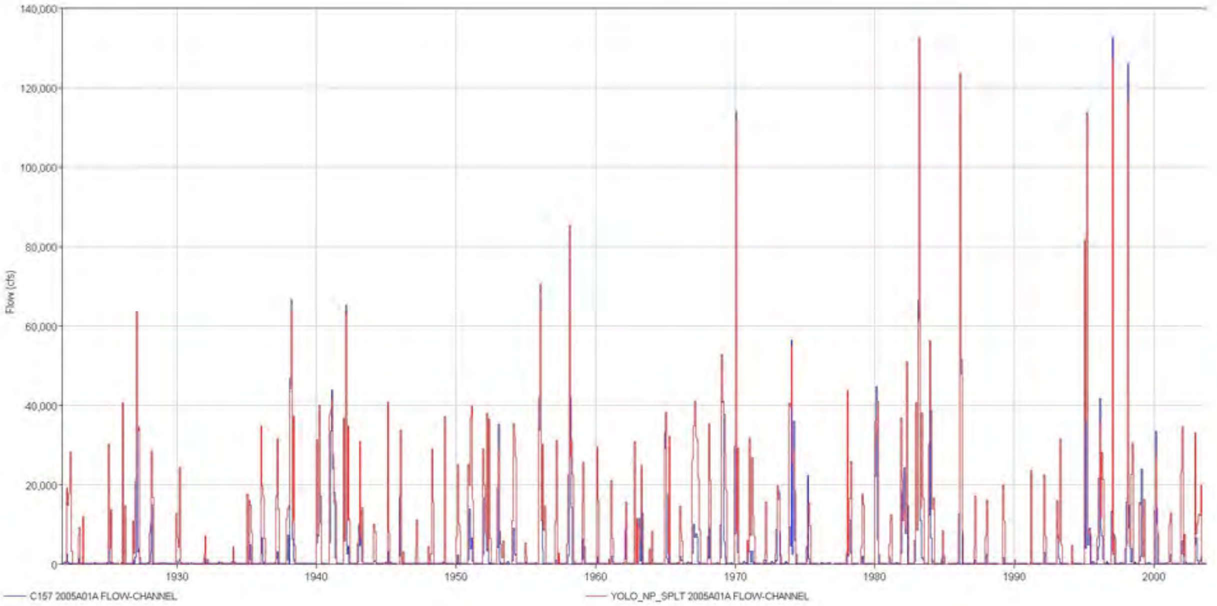


Figure 2 Comparison of Yolo Bypass inflow to the Delta for the current conditions (blue) and the Without Project C2 scenario (red)

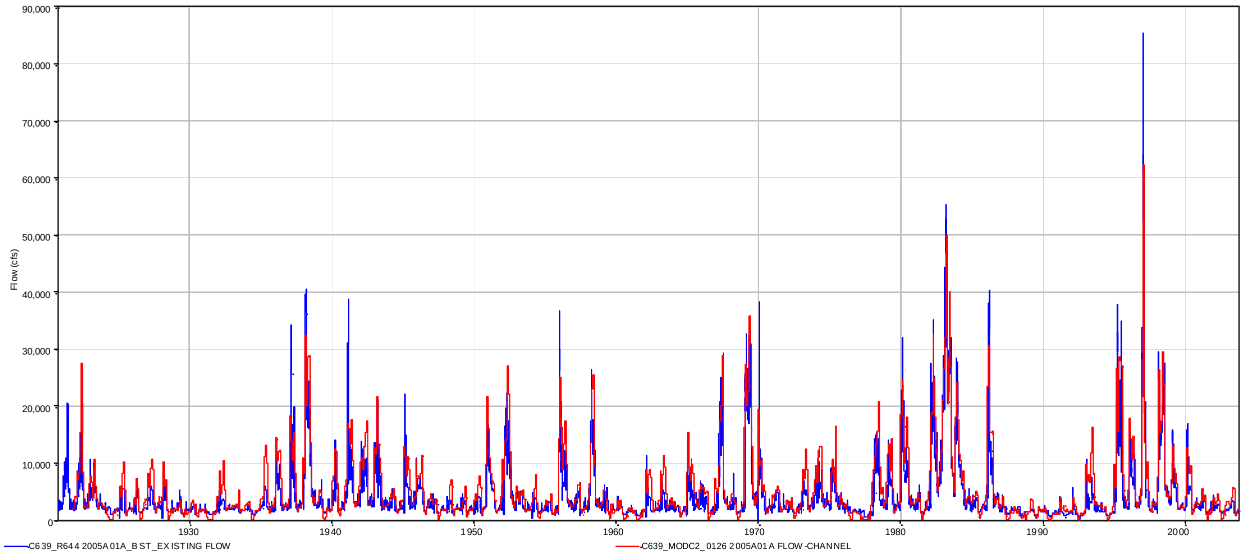


Figure 3 Comparison of San Joaquin River inflow to the Delta for current conditions (Scenario A, blue) and the Without project C2 scenario (red)

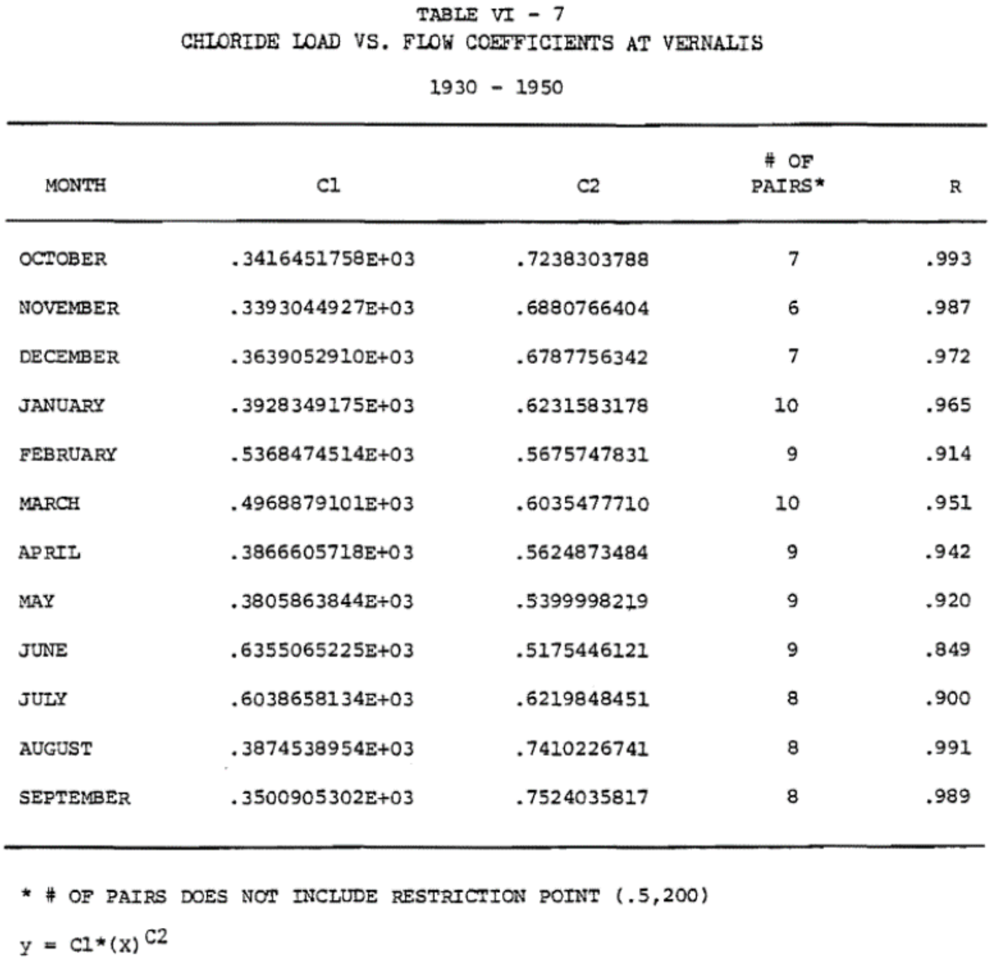


TABLE VI - 7
CHLORIDE LOAD VS. FLOW COEFFICIENTS AT VERNALIS

1930 - 1950

MONTH	C1	C2	# OF PAIRS*	R
OCTOBER	.3416451758E+03	.7238303788	7	.993
NOVEMBER	.3393044927E+03	.6880766404	6	.987
DECEMBER	.3639052910E+03	.6787756342	7	.972
JANUARY	.3928349175E+03	.6231583178	10	.965
FEBRUARY	.5368474514E+03	.5675747831	9	.914
MARCH	.4968879101E+03	.6035477710	10	.951
APRIL	.3866605718E+03	.5624873484	9	.942
MAY	.3805863844E+03	.5399998219	9	.920
JUNE	.6355065225E+03	.5175446121	9	.849
JULY	.6038658134E+03	.6219848451	8	.900
AUGUST	.3874538954E+03	.7410226741	8	.991
SEPTEMBER	.3500905302E+03	.7524035817	8	.989

* # OF PAIRS DOES NOT INCLUDE RESTRICTION POINT (.5,200)

$y = C1*(x)^{C2}$

Figure 4 Coefficients relating salt load and flow, estimated for each month. Source: Effects of the CVP upon the Southern Delta Water Supply, Sacramento-San Joaquin River Delta, California, prepared jointly by the Water and Power Resources Service and the South Delta Water Agency, June 1980.

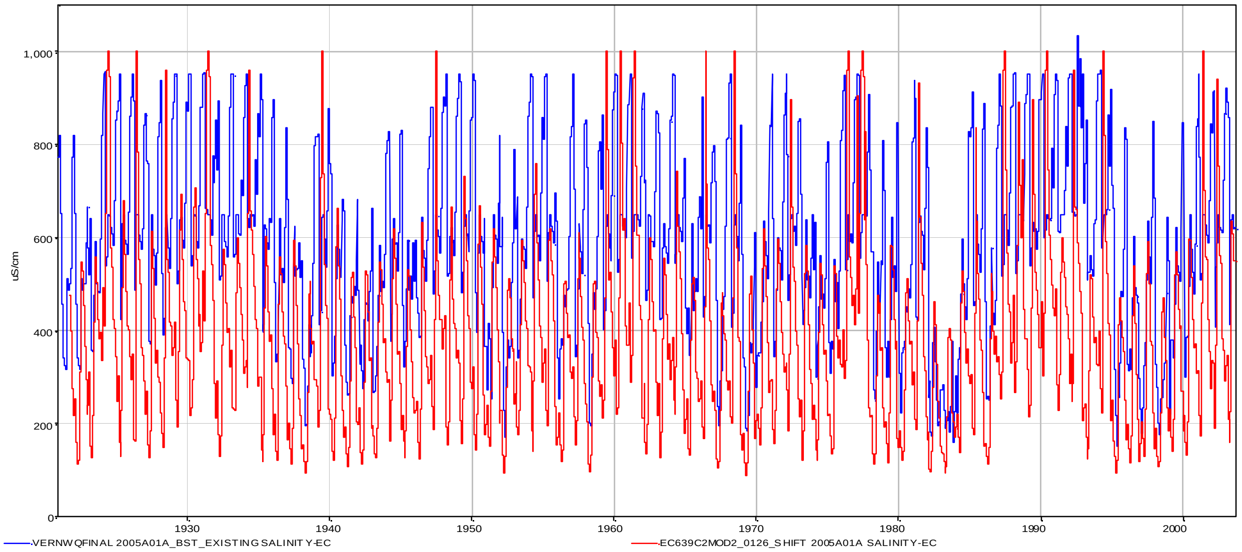


Figure 5. *Estimated EC at Vernalis current conditions (Scenario A, blue) and without Project (Scenario C2, red).*

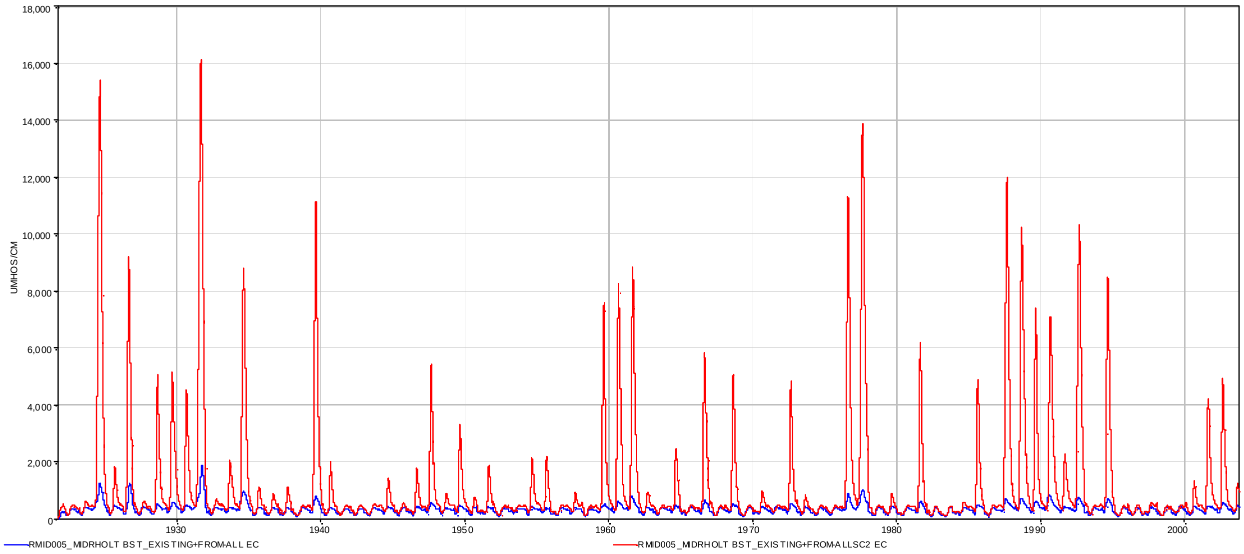


Figure 6 *DSM2 simulated EC at Middle River @ Holt (Rmid005) under the C2 scenario (red), and comparison to Scenario A (blue).*

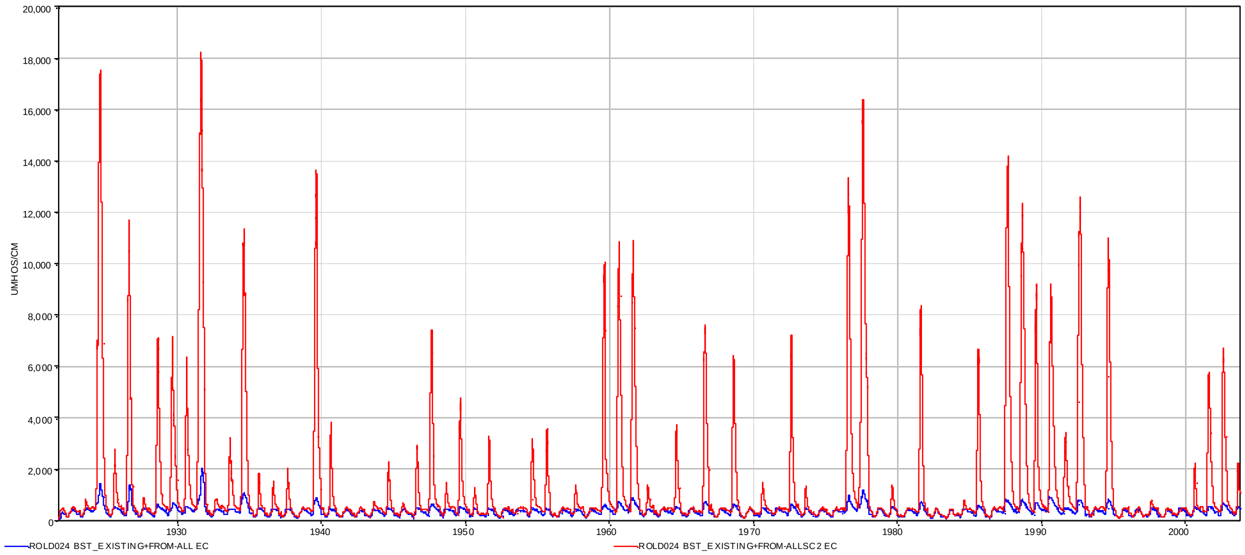


Figure 7 *DSM2 simulated EC at Old River at Bacon Island (Rold024) under the C2 scenario (red), and comparison to Scenario A (blue).*

3. USING THE DELTA SALINITY GRADIENT (DSG) MODEL TO FIT DSM2 DATA IN THE SOUTH DELTA

The Delta Salinity Gradient (DSG) model has been developed to represent salinity in the Western Delta as a function of the time history of freshwater inflow.[4] The DSG model, however, has not been focused on salinity in the southern Delta. In the present analysis, DSM2 output in the South Delta was used to calibrate DSG models for Scenario C2, as described in Chapters 1 and 2. A DSG model for Scenario A was performed in a similar manner; those results are presented in Appendix B.

Starting with the daily electrical conductivity outputs from DSM2, we made several refinements to narrow the scope of the dataset such that it is primarily relevant to (1) the Southern Delta alone, and (2) to the intrusion of seawater rather than other sources of salinity, e.g., agricultural runoff from the San Joaquin valley. Based on coordinates of the DSM2 nodes, distances from Golden Gate were computed along the river channels (Figure 8). DSM2 nodes along the San Joaquin (SJ), Middle (MID), and Old (OLD) rivers further than 85km inland were retained for analysis with the DSG model. The DSG model was fitted separately for the three river channels, and all data were considered from 85 km inland to the defined end of the corresponding channel (for the San Joaquin River 184.4 km; for the Old River 176.8 km; and for the Middle River 157.7 km). As shown in Figure 8, a portion of the distance for the Old and Middle River channels overlaps with the San Joaquin river channel. Thus, data from 85 km to 118.5 km on San Joaquin River channel were included in the fitting process for the Middle River DSG model. Similarly, data from 85 km to 114.5 km on the San Joaquin River channel were used in the fitting for the Old River DSG model.

---

[4] Hutton, P.H., J. S. Rath, L. Chen, M. J. Ungs, and S. B. Roy (in review) Nine Decades of Salinity Observations in the San Francisco Bay and Delta: Modeling and Trend Evaluation. ASCE Journal of Water Resources Planning and Management.

The input flows (actual flow and antecedent G-flow) for the C2 Scenario are shown in time series form in Figure 9, and as a distribution in Figure 10.

The DSM2 output often displayed a non-monotonic salinity gradient, with salinity decreasing from the western model boundary through portions of the Delta and then increasing again further inland. This is hypothesized to be due to elevated salinity in San Joaquin inflows. To mitigate this phenomenon's effects on estimation of DSG model parameters, we only trained the DSG model using data from nodes west of the node with the minimum salinity on a given day, reach, and scenario. It is acknowledged that this rather simple filter is imperfect and perhaps merits further refinement, in light of the extreme hydrology associated with scenario C2, but appears to give reasonably good results.

The DSG model was fitted using the actual flows at Martinez based on daily DSM2 output, which display a tidal influence rather than the monthly NDOI values computed from DSM2 input. The monthly NDOI values were found to be insufficient to explain the daily EC values.

An antecedent flow, G, dataset was calculated using the each scenario's flow (Q) time series, in this case the flow at Martinez. The β parameter related to this calculation is the same as for the current calibration of the DSG model to EC data in the western Delta. As the primary flow regime of interest for this analysis is lower flows with higher salt intrusion, we are not using the variable ocean boundary salinity that was introduced to the DSG model to deal with suppression of near-ocean ECs under high outflows. In other words, the parameter γ is left fixed at positive infinity. Also, recognizing that the region of interest has generally lower salinities than the western Delta, we centered the representation of the gradient in the model around the isohaline X_C corresponding to the adjustable EC value S_C. Currently, this parameter is not statistically estimated but instead left at an illustrative value of 2 mS/cm.

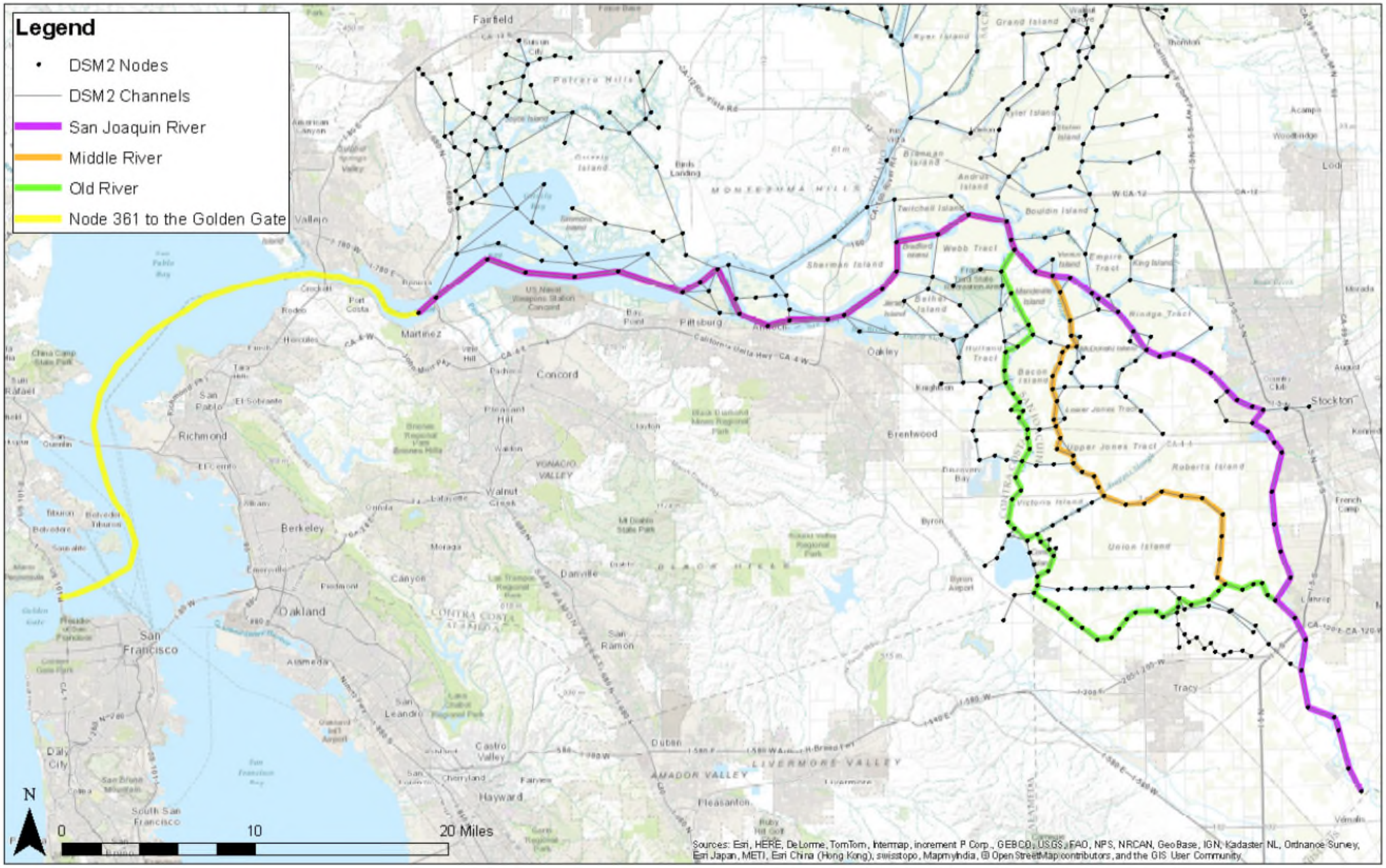
The first attempt at fitting tried to only estimate the parameters ϕ_1 and ϕ_2, leaving the boundary salinities at the values in the current calibration of the DSG model for the western Delta—$S_b = 0.2$ mS/cm and $\hat{S} = 53$ mS/cm, but this resulted in unsatisfactory fits. Allowing them to be estimated freely resulted in less biased fits, although the theoretical appeal of a prescribed, a priori boundary value is lost. Two different estimation procedures were tried: numerical non-linear least squares (nls) and maximum a posteriori (map) fit of a Bayesian student's t model. The fitting procedures give slightly different results (Table 2). A fully Bayesian estimate of $\hat{S}$ for the San Joaquin C2 model (only performed for one scenario due to computational intensity) allows for comparison with the estimated "boundary salinity" with the range of DSM2 values. Figure 11 confirms the estimate is near the maximum EC; the rare cases where the training data are above the $\hat{S}$ estimate seem okay in the context of the Bayesian model being an estimate of the *center* of EC distribution conditional on a given antecedent flow.

Figure 12 shows the calculated values of salinity from the fitted DSG models for the Old, Middle, and San Joaquin River for an illustrative range of G-glows. Figure 13 through Figure 16 illustrate the spatial and flow variability of the fitted model in various ways and compare it to DSM2 data used in training. Figure 17 is a direct comparison of model predictions with training data.

Table 2

Diagnostics of DSG predictions of DSM2-simulated EC for Scenario C2 in terms of a linear model $EC_{DSM} = a + b \cdot EC_{DSG}$ and best fit DSG parameters for two different estimation procedures: non-linear least squares (nls) and maximum a posteriori (map) fit of a Bayesian student's t model. Columns in gray are not estimated in model training.

Scenario	Reach	Fit	Model Diagnostics				DSG Parameters (EC units: mS/cm, flow units: cfs)							
			r^2	Std. Error	a	b	ϕ_1	ϕ_2	S_b	$\hat{S}$	S_C	γ	δ	$\beta \times 10^{-10}$
C2	MID	map	0.91	1.25	0.20	0.98	679	-0.230	0.377	25.9	2.00	∞	1.00	1.5
C2	MID	nls	0.91	1.24	0.00	1.00	691	-0.230	0.527	25.0	2.00	∞	1.00	1.5
C2	OLD	map	0.93	1.08	0.12	0.99	766	-0.244	0.351	26.0	2.00	∞	1.00	1.5
C2	OLD	nls	0.94	1.08	0.00	1.00	734	-0.238	0.435	25.3	2.00	∞	1.00	1.5
C2	SJ	map	0.93	1.10	0.12	0.98	537	-0.203	0.325	26.2	2.00	∞	1.00	1.5
C2	SJ	nls	0.93	1.10	0.00	1.00	511	-0.195	0.408	25.1	2.00	∞	1.00	1.5



Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Figure 8 Distances for DSM2 nodes from Golden Gate Bridge for the Old, Middle and San Joaquin Rivers, estimated along the channels used in DSM2.

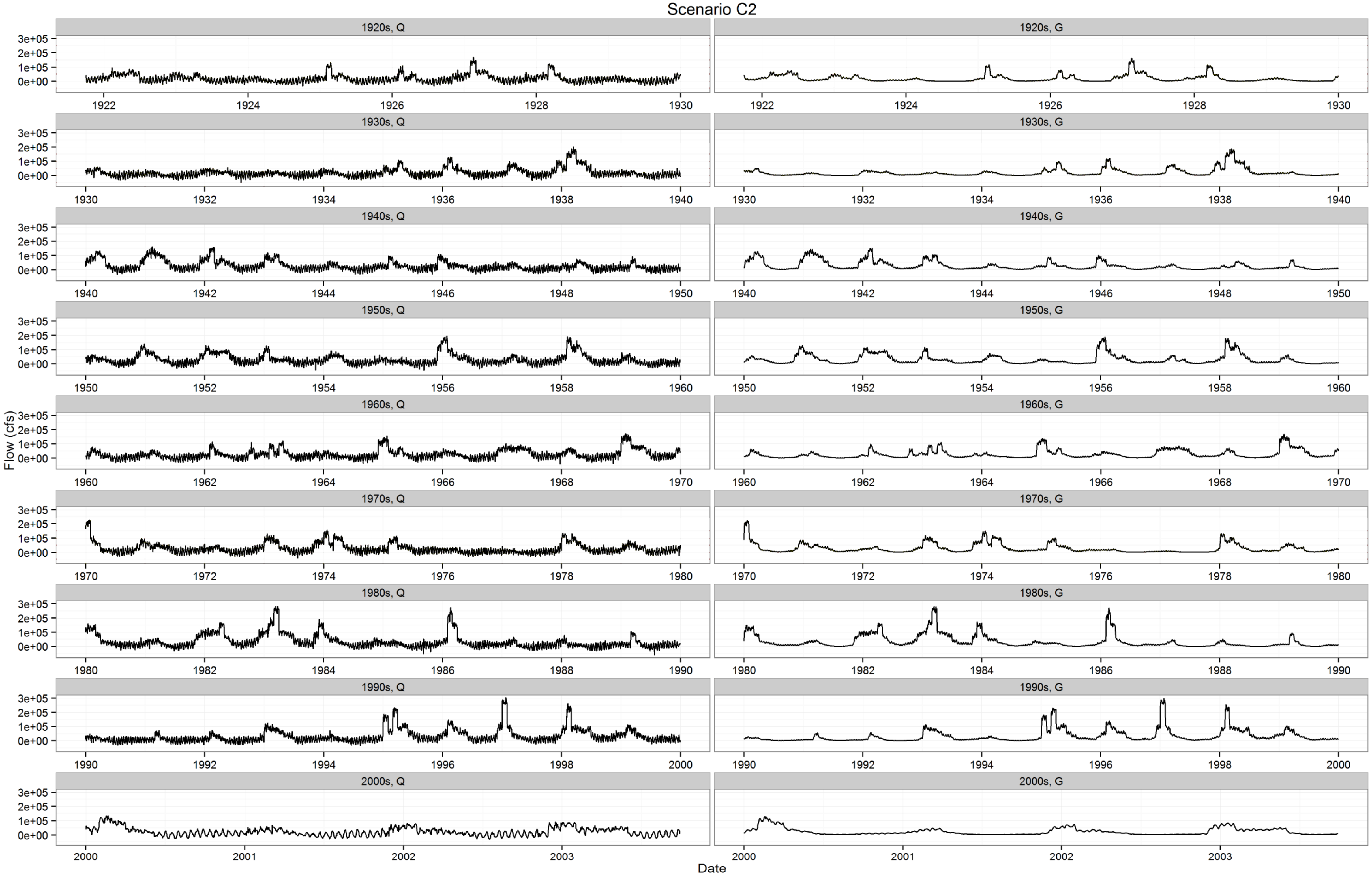


Figure 9 Time series plots of net Delta outflow, Q, approximated as modeled flow past Martinez, and corresponding antecedent flows, G, for Scenario C2.

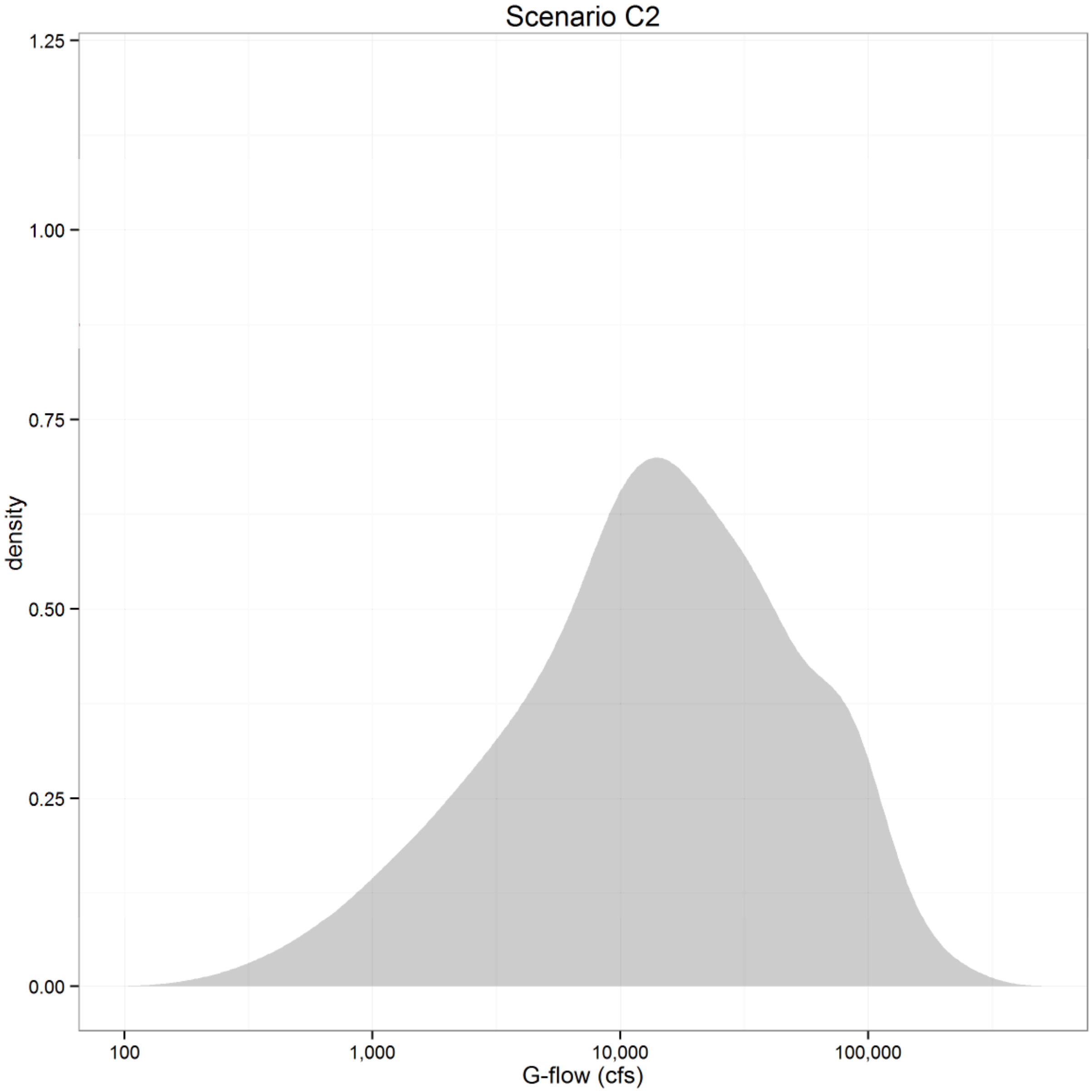


Figure 10 Scenario C2 smoothed frequency distribution of G-flow.

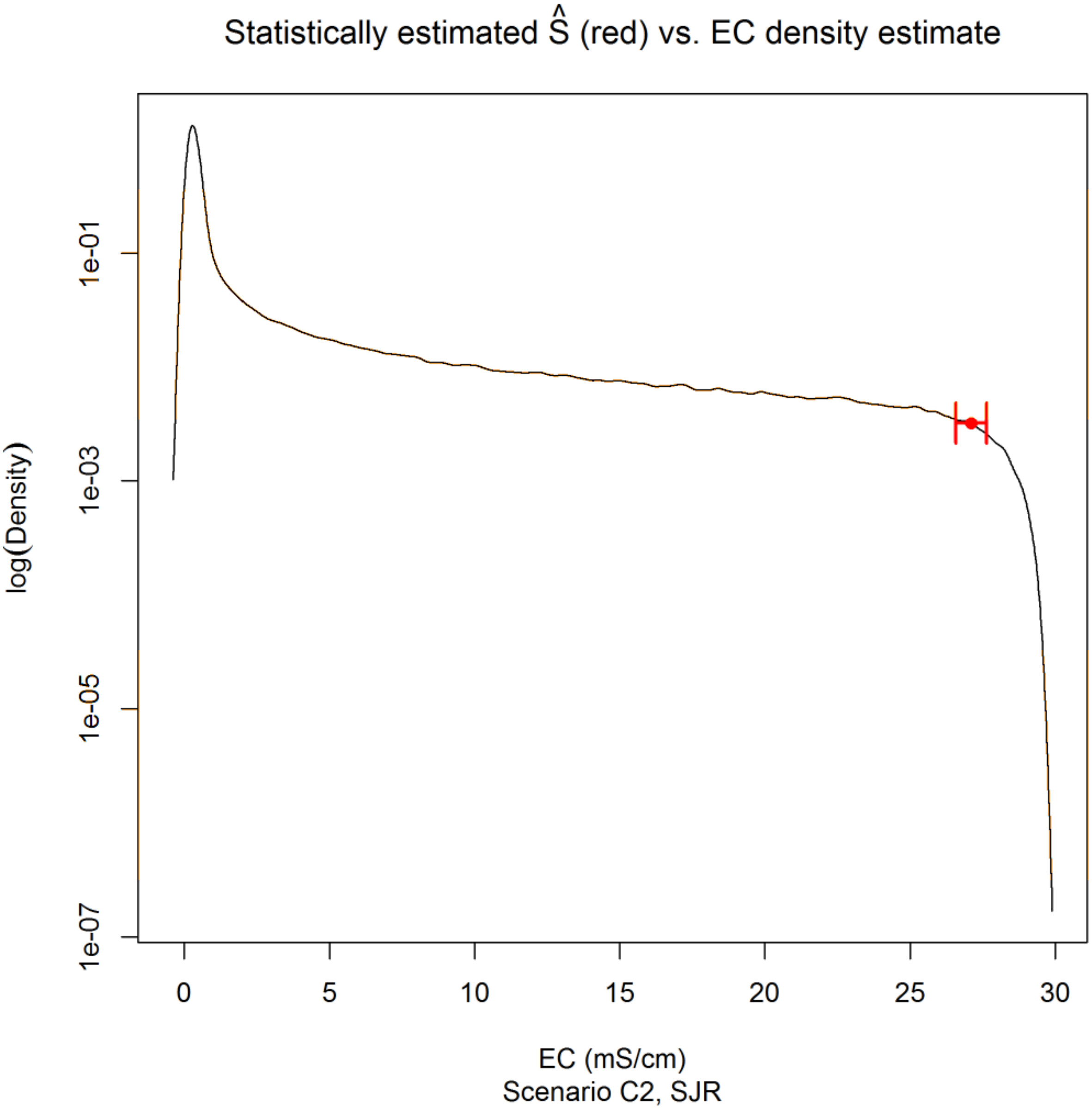


Figure 11 Illustrating the estimation of $\hat{S}$ as a free parameter—the posterior mean with a 95% interval (shown in red) is close to the maximum DSM2 simulated EC.

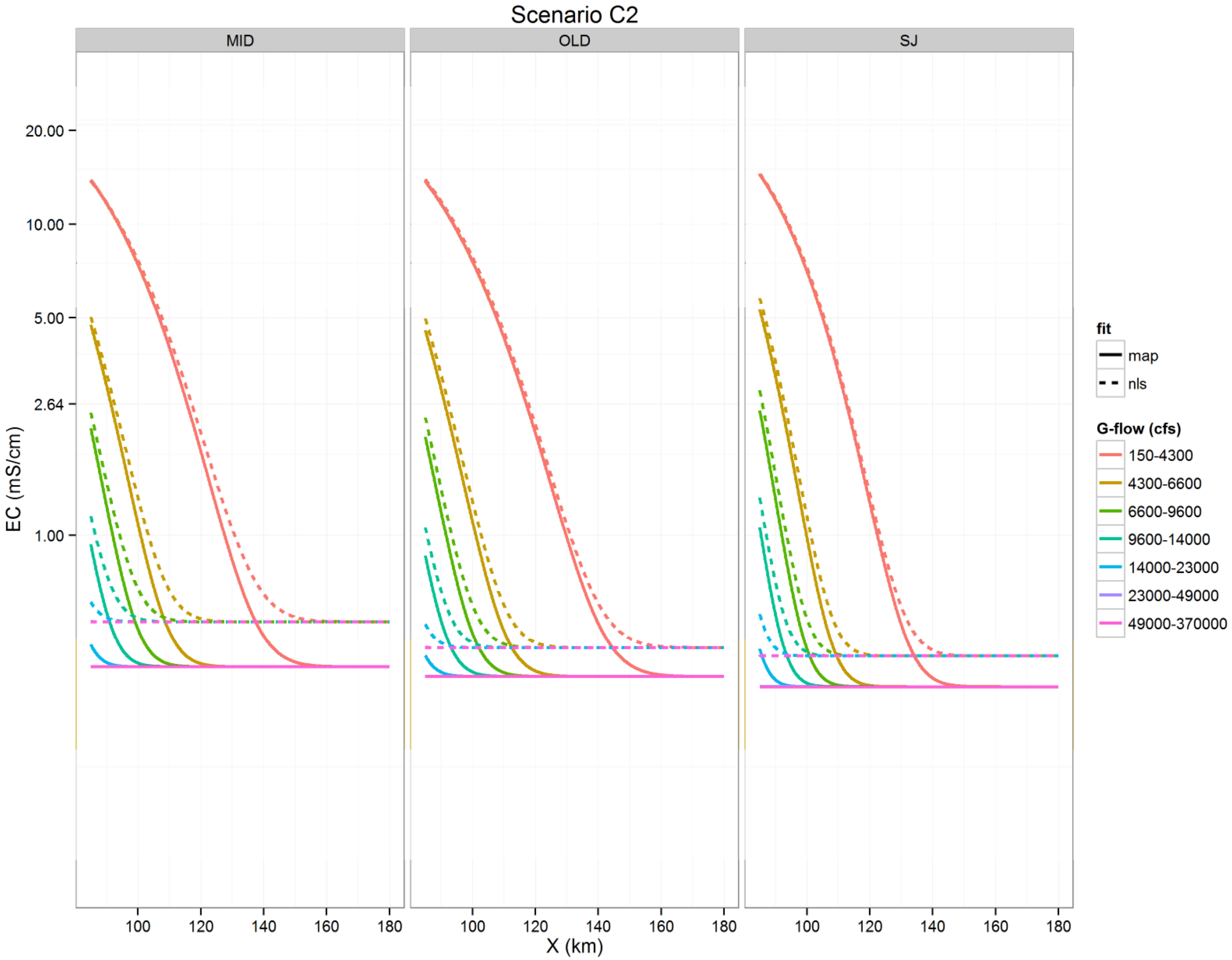


Figure 12 *Illustration of spatial variation in DSG predictions using the median G-flow in seven evenly spaced (in terms of G-flow percentiles) flow bins.*

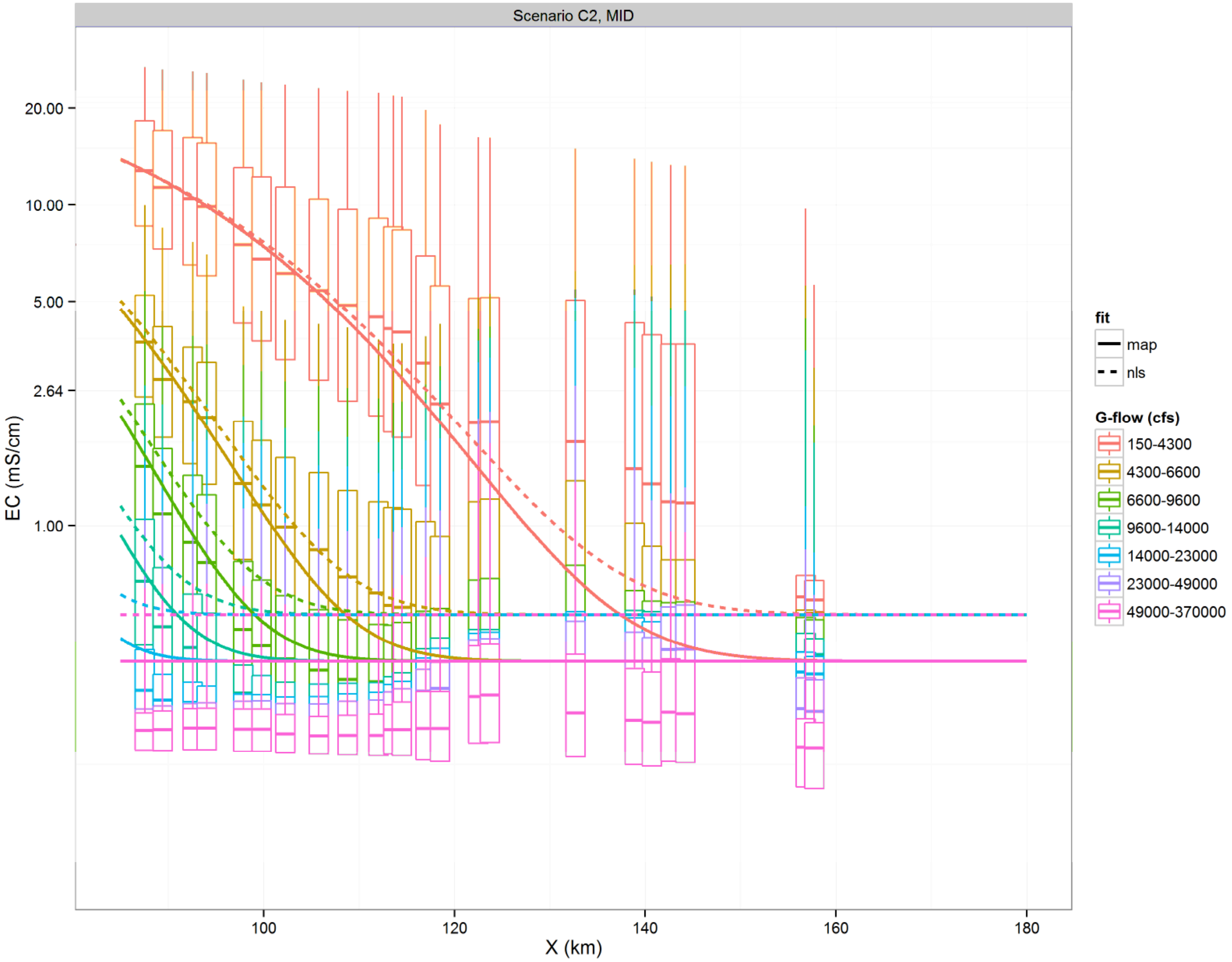


Figure 13 As in Figure 12, except with box plots showing the distribution of DSM2 data at each distance. Scenario C2, Middle River.

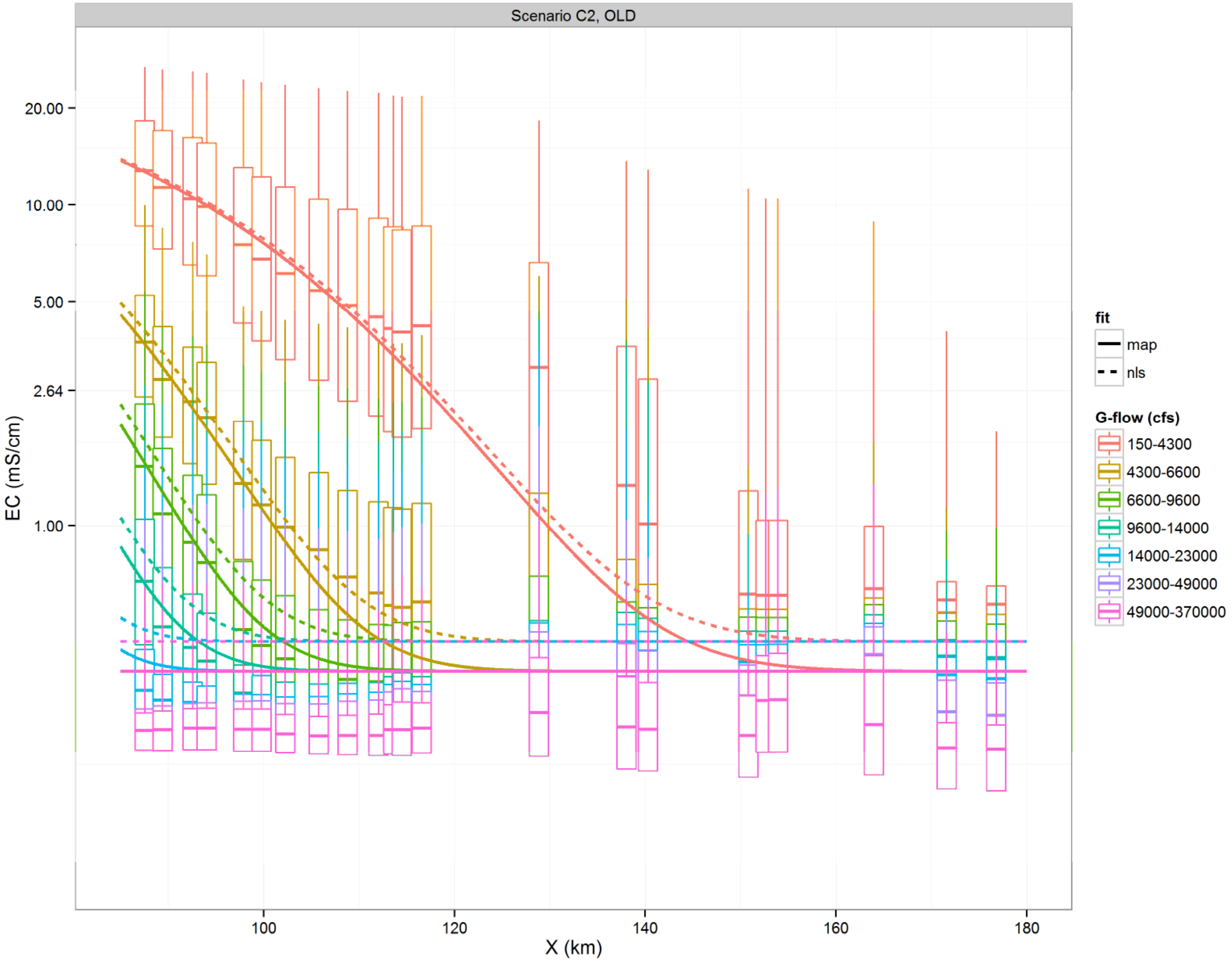


Figure 14 As in Figure 12, except with box plots showing the distribution of DSM2 data at each distance. Scenario C2, Old River.

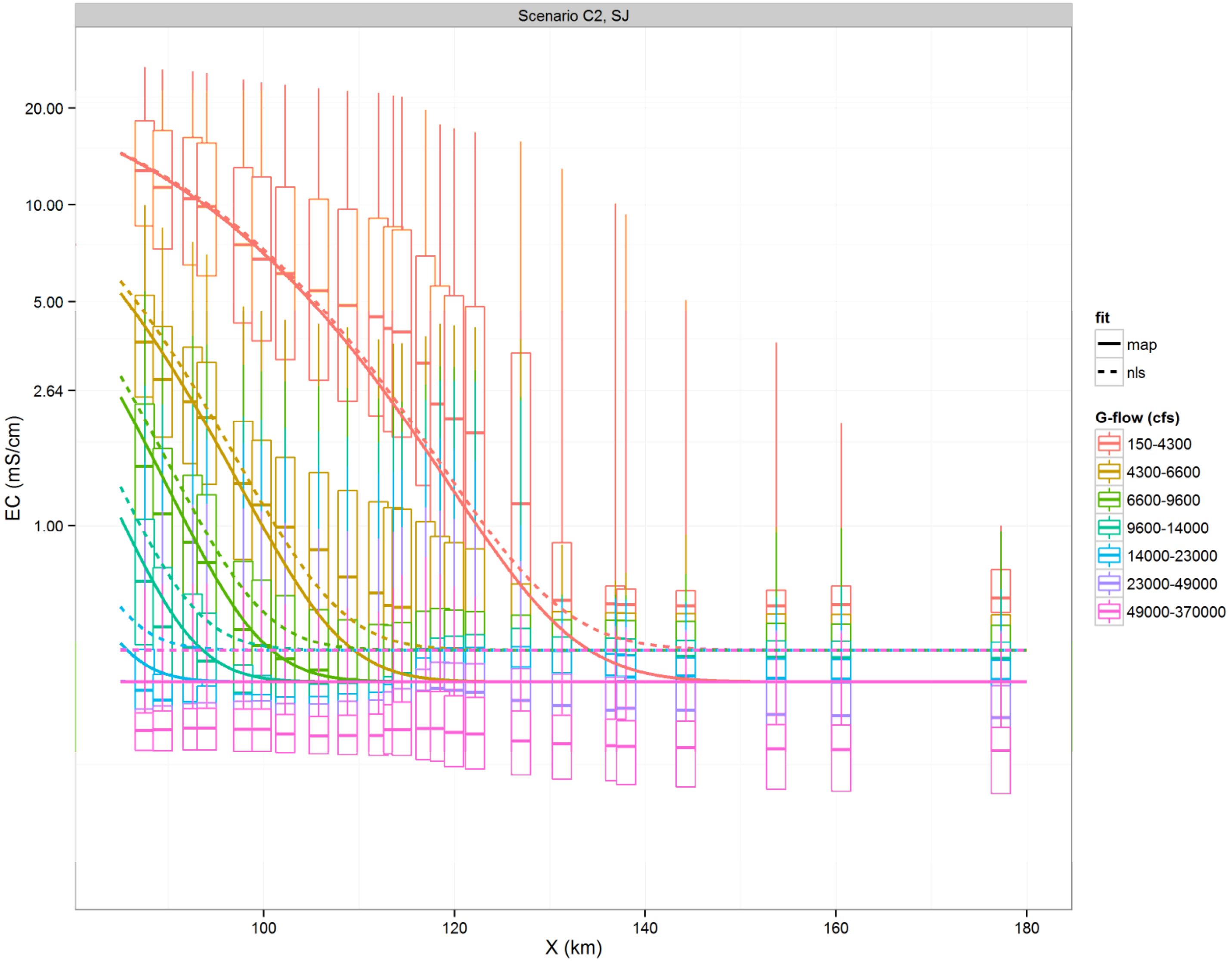


Figure 15 As in Figure 12, except with box plots showing the distribution of DSM2 data at each distance. Scenario C2, San Joaquin River

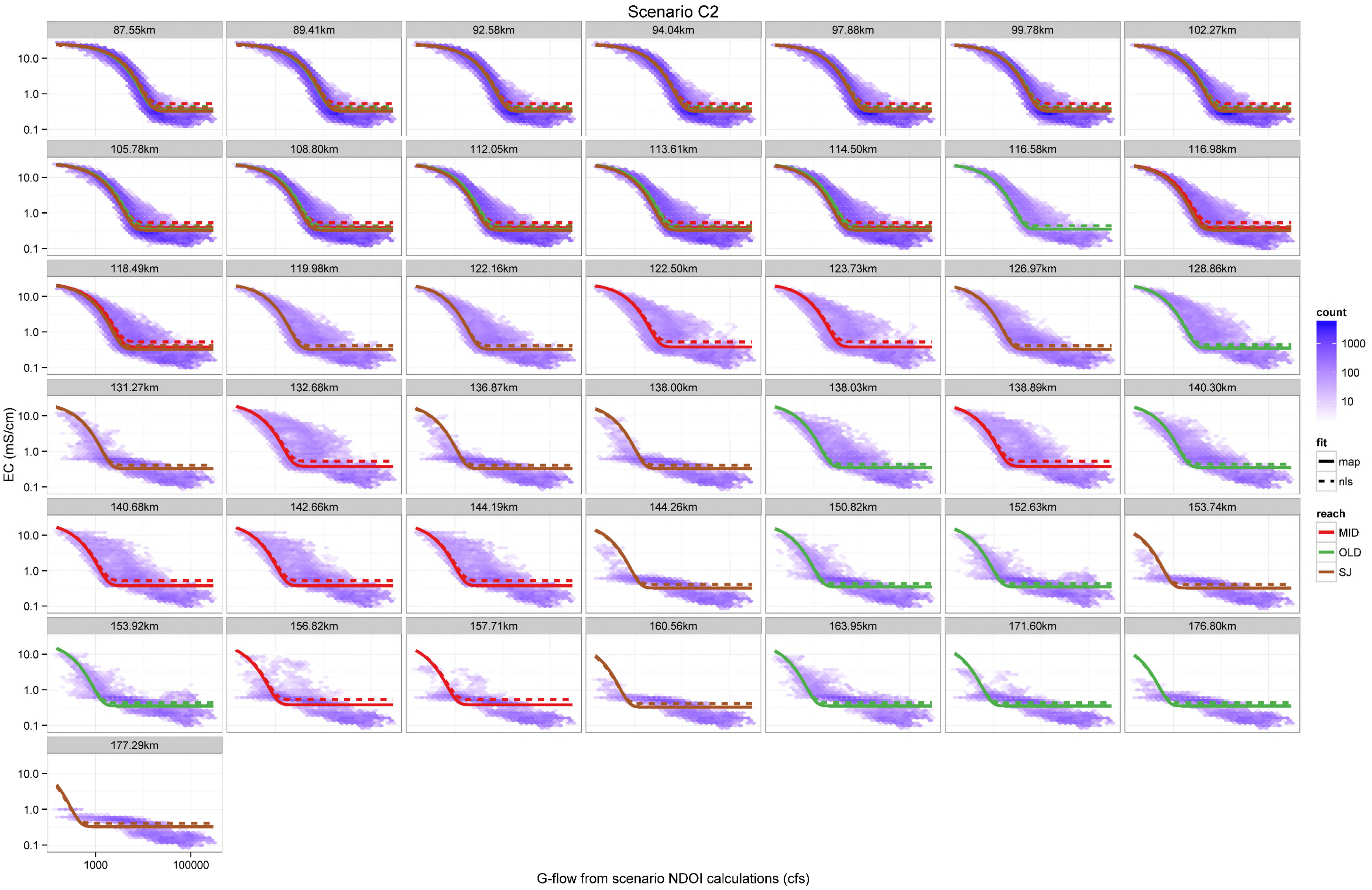


Figure 16 Flow response of DSM2 simulations and DSG predictions of EC at each DSM 2 location, Scenario C2. Log scale on both axes.

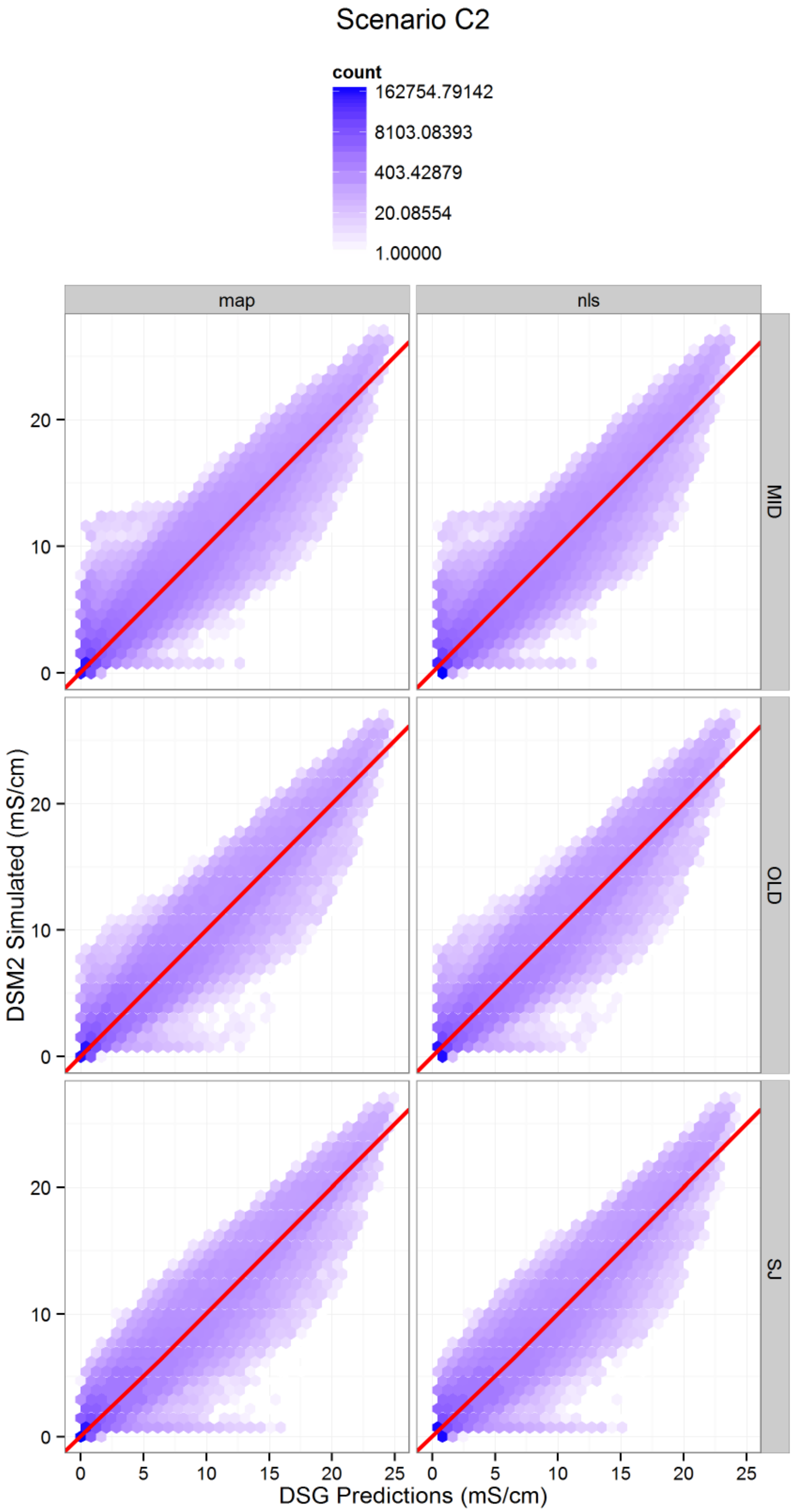


Figure 17 DSG predictions vs training data and 1:1 line (red).

4. VALIDATION OF DSM2 AND DSG MODEL RESULTS

The DSM2 model has not been calibrated for flow and salinity conditions that occurred in the early decades of the 20th century, which include some extremely dry conditions in the 1920s and early 1930s. To build confidence in the application of DSM2 to low flow conditions observed in the without Project scenario, we performed a limited validation using observed salinity data from the South Delta,[5] and using the DSG model that was calibrated to the Without project C2 Scenario.

To compare the model and data, we related EC and distance, where individual plots were developed for a range of G-flow values from 500 to 4,500 cfs in increments of 500 cfs. Each plot contained observed data points from either WY1922-1944 or WY1922-1968, as long as the observed data fell in the identified G-flow range. Each plot shows the DSG model line for the three river channels, calculated using the mid-point G-flow value. Thus, the plot for 500-1,000 cfs shows DSG plots for 750 cfs. Overall, this exercise shows that the DSG model is a reasonable representation of the data, even at some of the most extreme low flow conditions observed in the 20th century. This provides support for the use of the re-calibrated DSG model and the DSM2 model in applications where Delta water quality behavior is to be modeled under conditions of very low flows.

---

[5] Tetra Tech (2015) Mapping and Trend Evaluation of Interior Delta Salinity, Final report prepared for the Metropolitan Water District of Southern California.

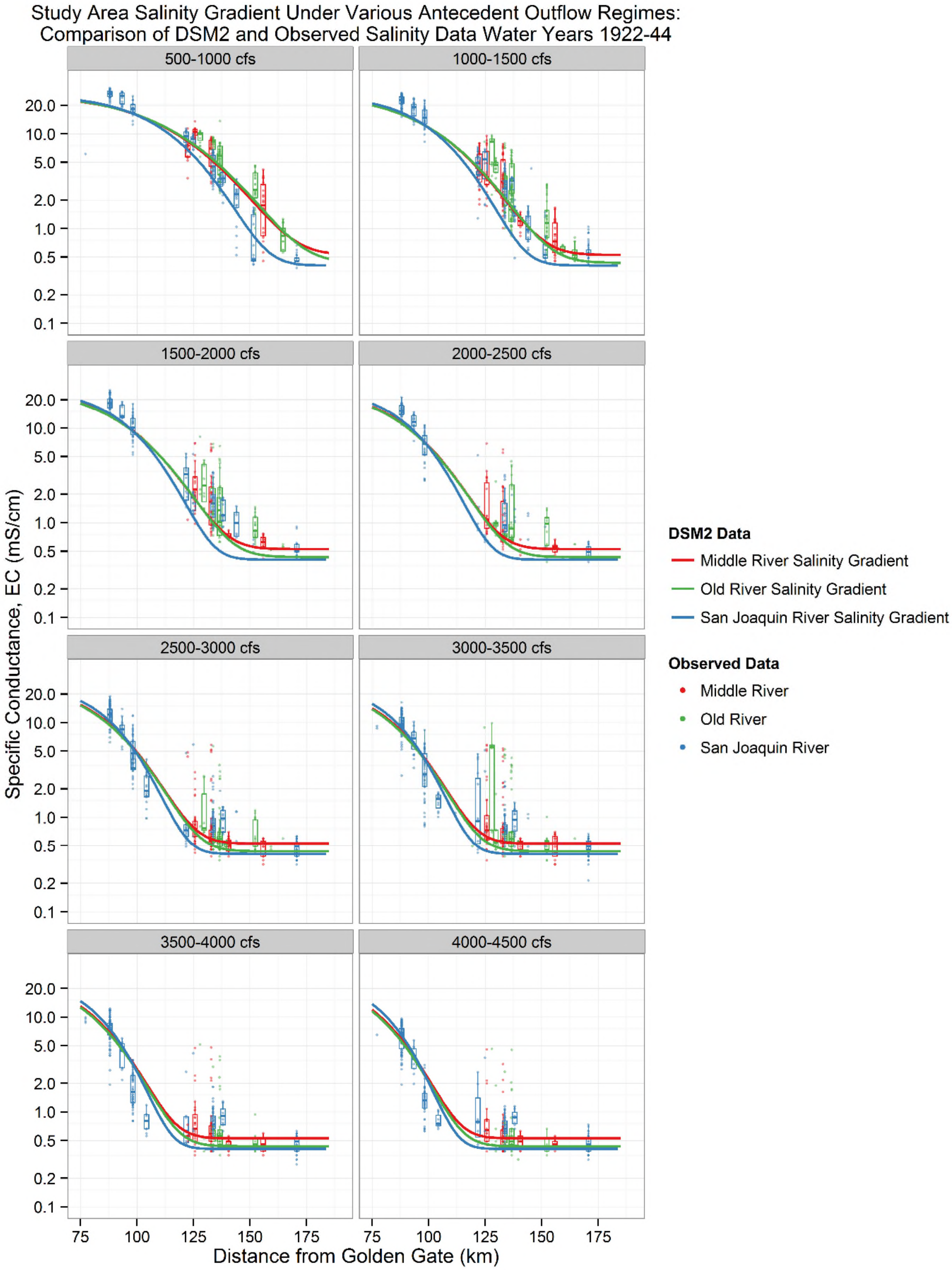


Figure 18 *Comparion of observed salinity data (1922-1944) and DSG model salinity for specified G-flow ranges.*

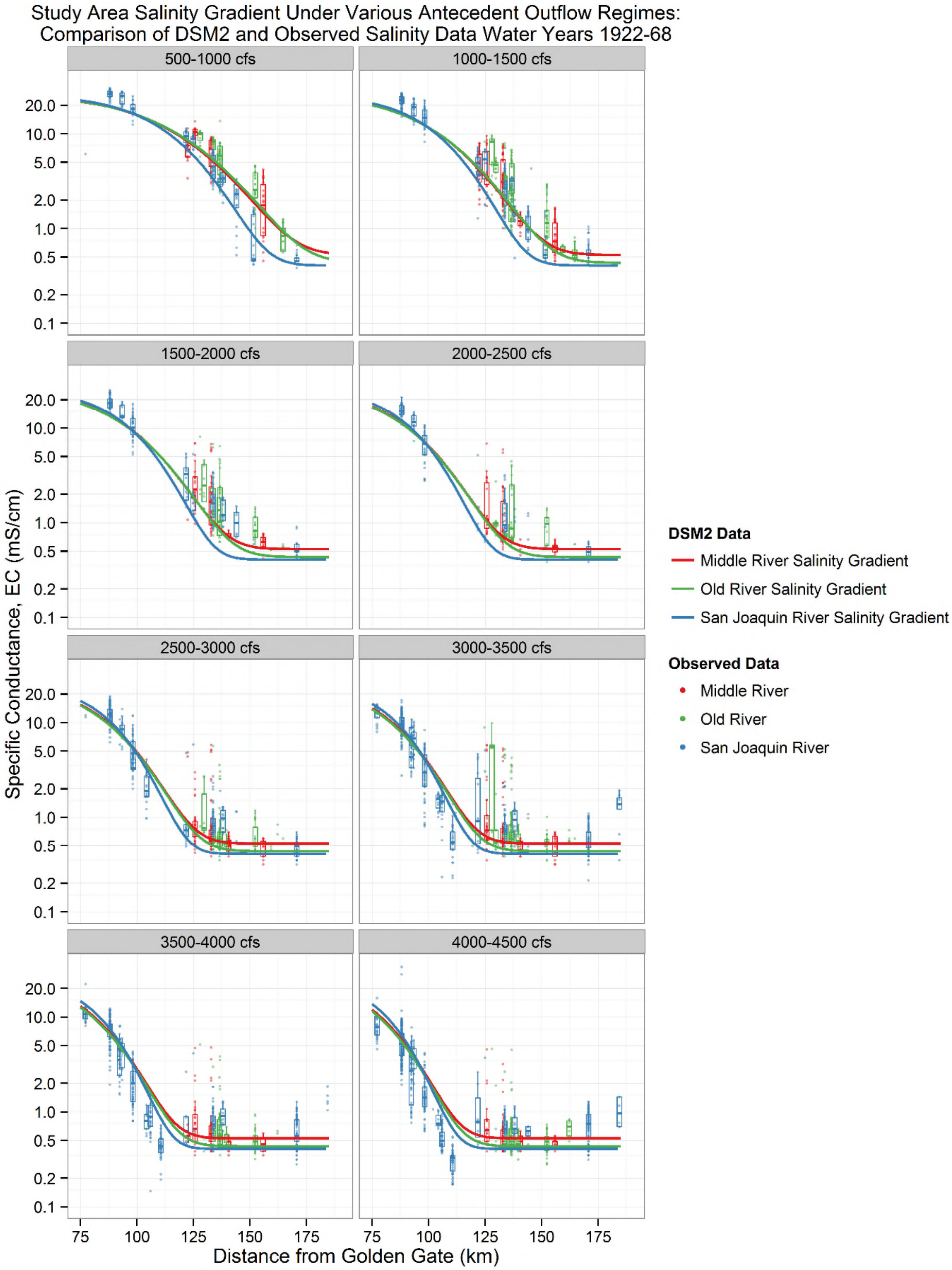


Figure 19 *Comparion of observed salinity data (1922-1968) and DSG model salinity for specified G-flow ranges.*

5. ESTIMATION OF AGRICULTURAL AREA BY DISTANCE FROM GOLDEN GATE

As part of this task, we computed the irrigated agricultural area by distance along the Old, Middle, and San Joaquin River channels south of the San Joaquin River. Data on agricultural land use in the Delta region was obtained from DWR.[6] The data consisted of discrete polygons or parcels of land across the entire Delta.

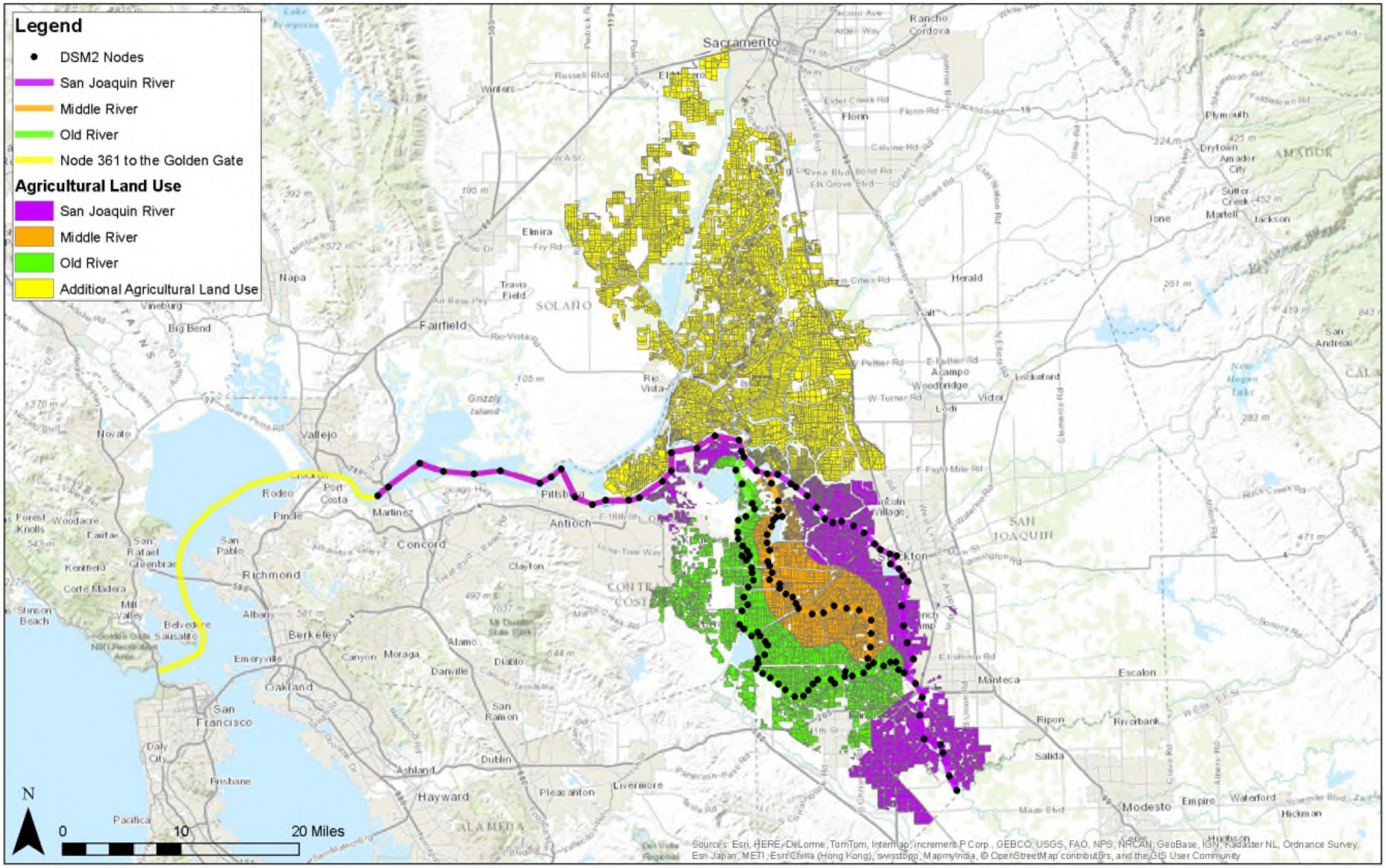
The agricultural land use parcels were divided up as follows. First, a buffer around each of the three rivers of interest was created. The buffer extended out 5 miles, except where there is less than 10 mile distance between neighboring rivers (including the Sacramento River, which was taken into consideration when assigning the land use, but not included in the analysis itself). Only areas south of the San Joaquin River were considered in this analysis, and some small, isolated pockets of land distant from the river channel were excluded. Where the Old, Middle, and San Joaquin Rivers are close together, the land was divided up approximately so that the land use polygons are assigned to the nearer river. The nearest DSM2 node was calculated for each land use polygon within each river stretch, and then assigned to it. This was accomplished using the simple nearest distance from polygon edge to node point. The acreage of agricultural land use was summed for each node, and accumulated as one moves upstream. This method is approximate where the rivers come together (some polygons assigned to one node might be better attributed to a different one on a different river), but everywhere else this approach works well at assigning polygons to the correct node.

A map showing the channels and the agricultural areas is presented in Figure 20. The total agricultural area in the Delta is 393,400 acres, of which 73,500 acres was associated with

---

[6] Jane Schafer-Kramer (2015) Personal Communication, April 3.

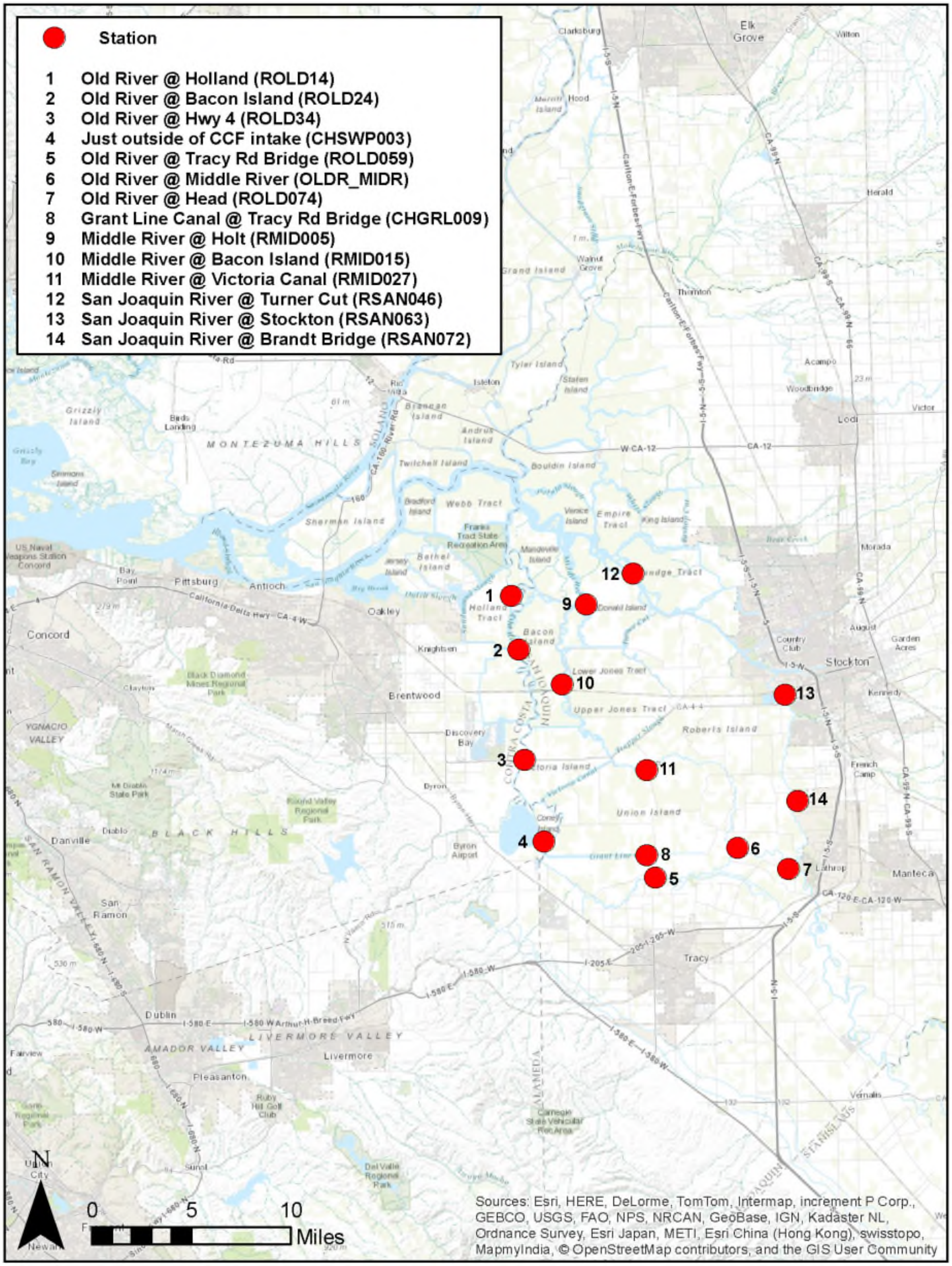
the San Joaquin River, 42,000 acres was associated with the Middle River, and 72,000 acres was associated with the Old River.



Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Figure 20 Agricultural area by river river channel.

APPENDIX A VOLUMETRIC FINGERPRINTS FOR WITHOUT PROJECT SCENARIOS WITH AND WITHOUT DELTA ISLAND CONSUMPTIVE USE



Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Figure 21 Map showing 14 stations used for plotting volumetric fingerprints in the following pages

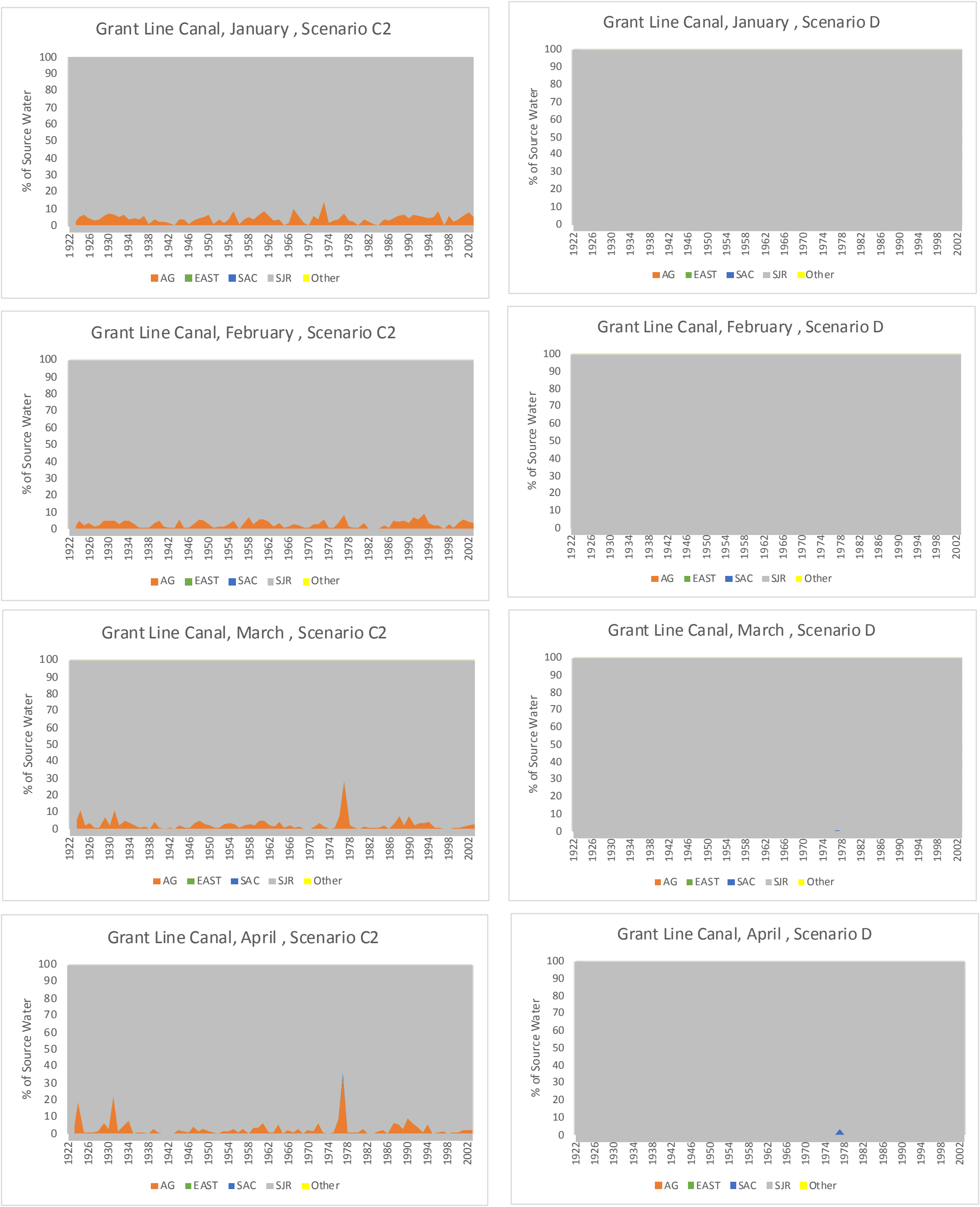
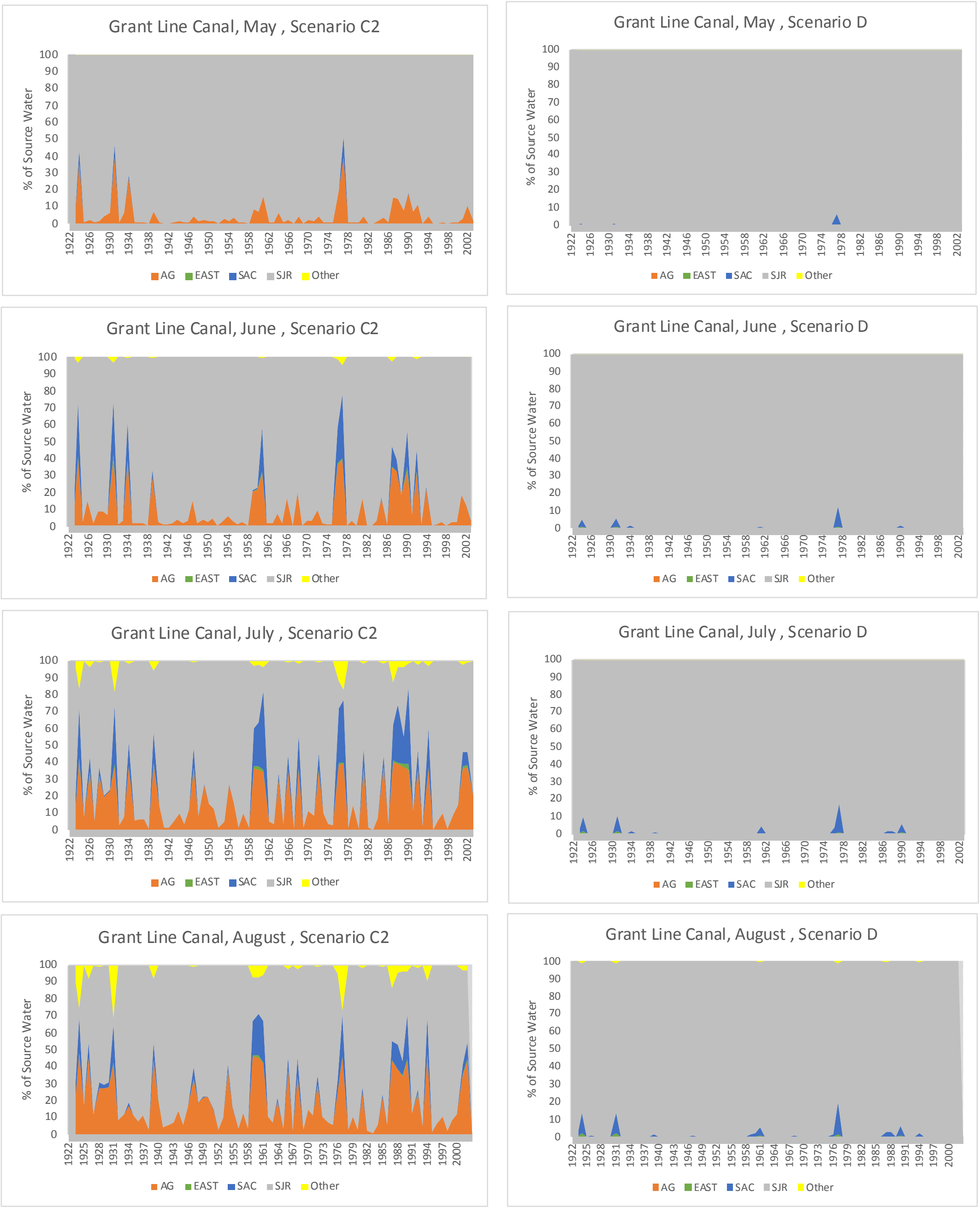


Figure 22 *CHGRL009: Grant Line Canal @ Tracy Rd Bridge*



Grant Line Canal, May , Scenario C2

Grant Line Canal, May , Scenario D

Grant Line Canal, June , Scenario C2

Grant Line Canal, June , Scenario D

Grant Line Canal, July , Scenario C2

Grant Line Canal, July , Scenario D

Grant Line Canal, August , Scenario C2

Grant Line Canal, August , Scenario D

Figure 23 CHGRL009: Grant Line Canal @ Tracy Rd Bridge

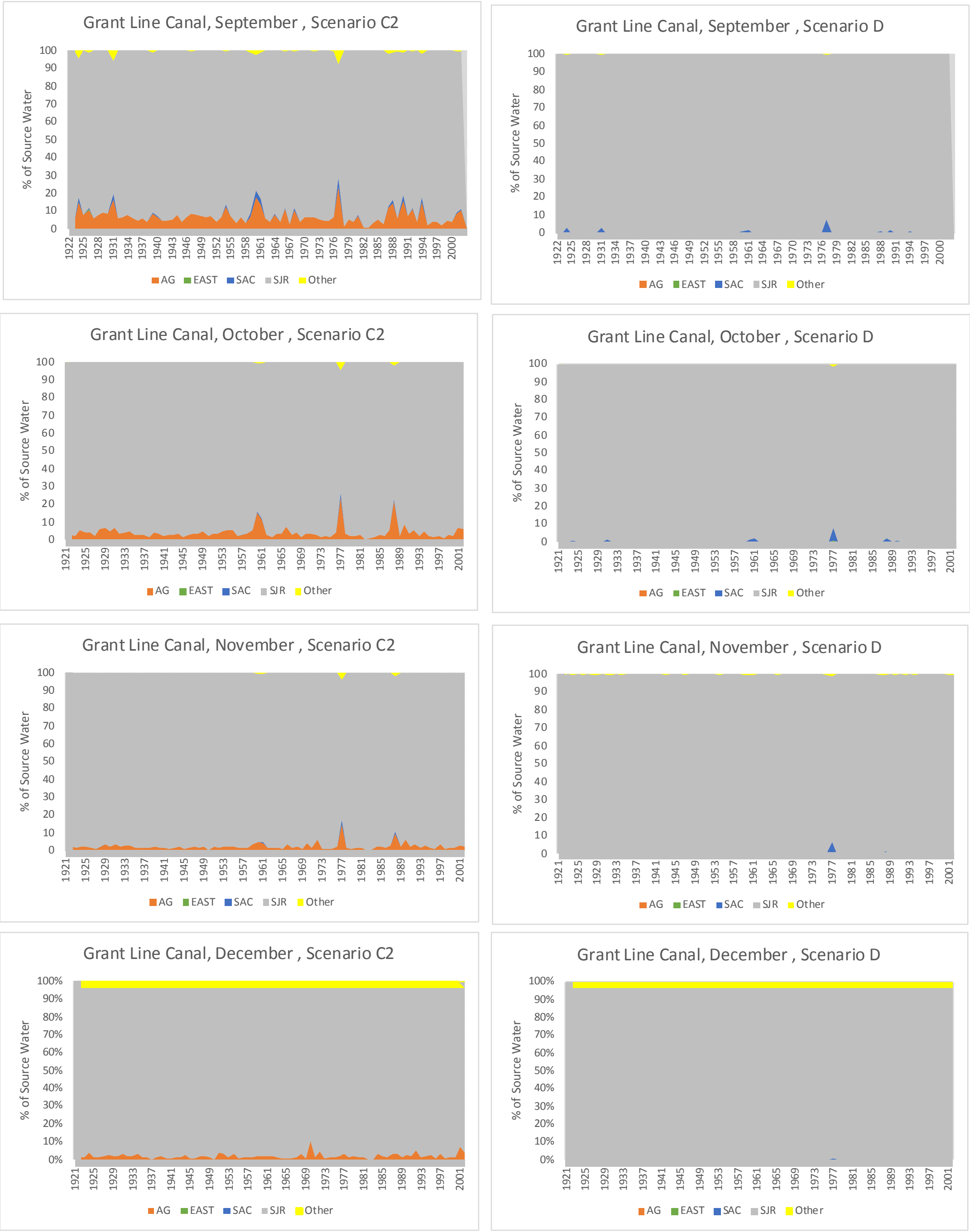


Figure 24 *CHGRL009: Grant Line Canal @ Tracy Rd Bridge*

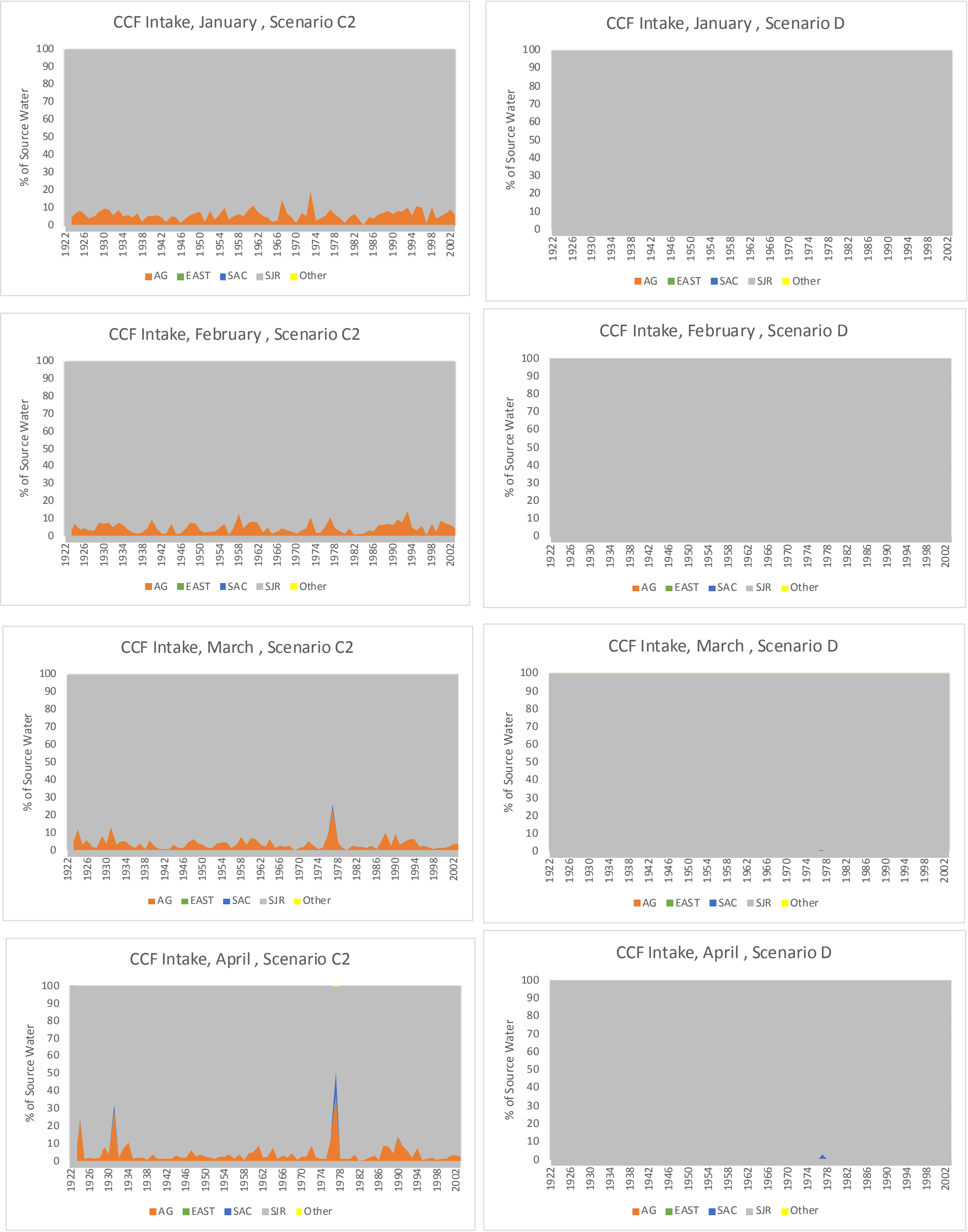


Figure 25 CHSWP003: CCF Intake

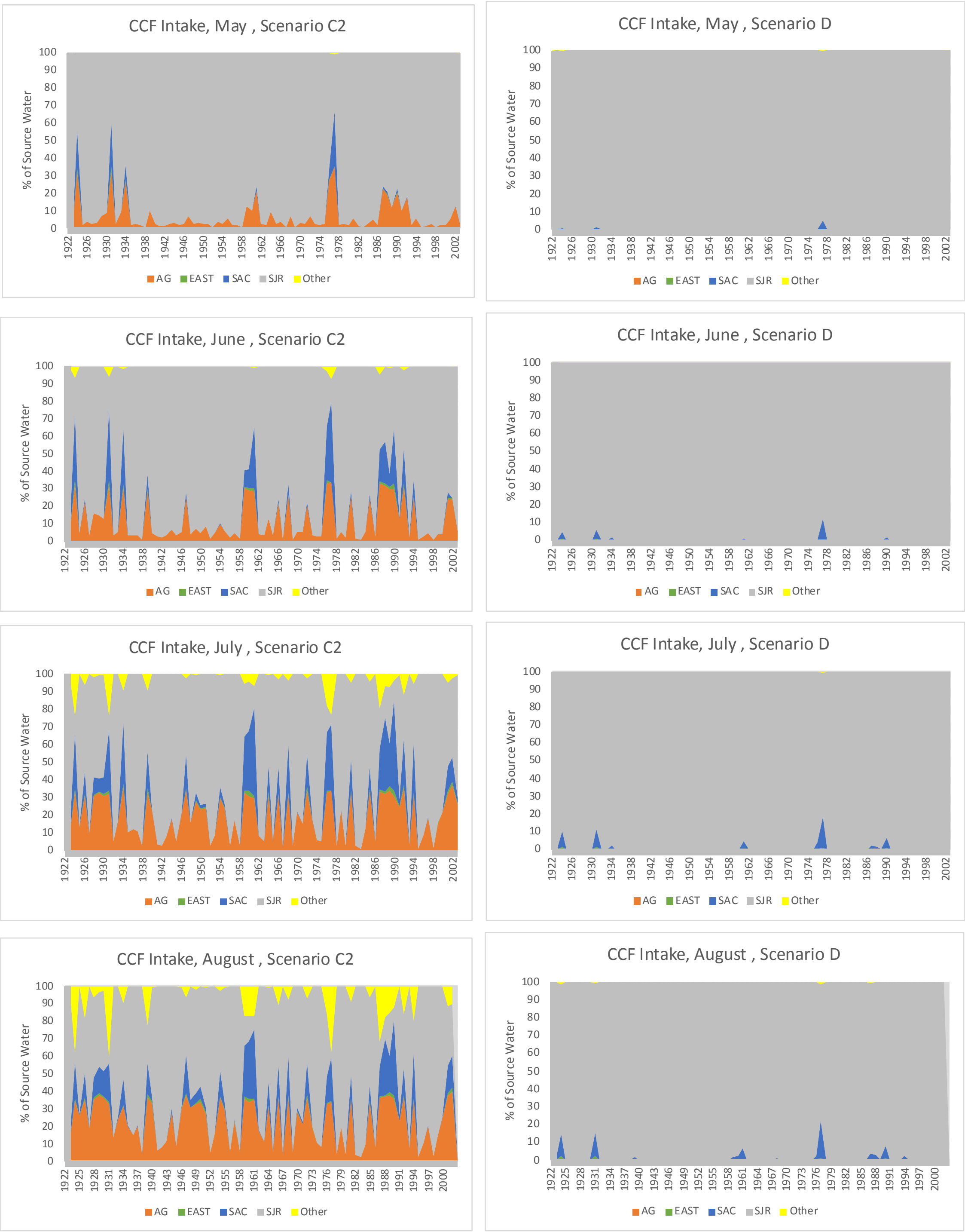
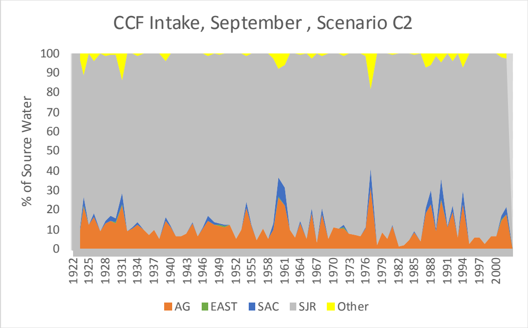
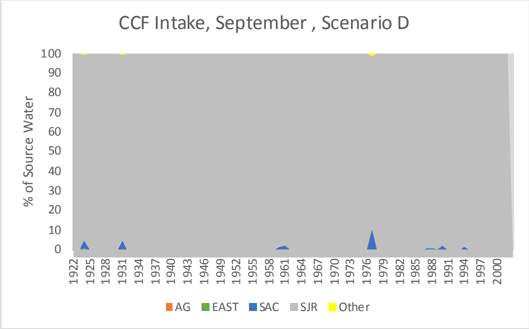
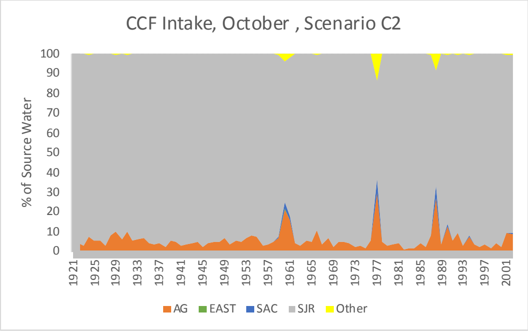
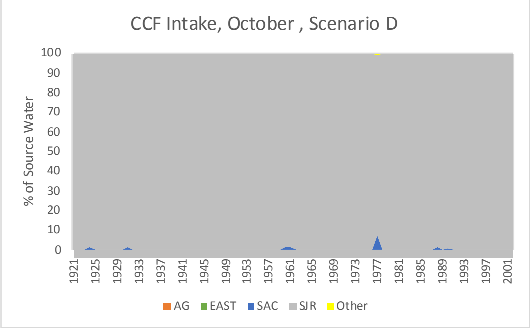


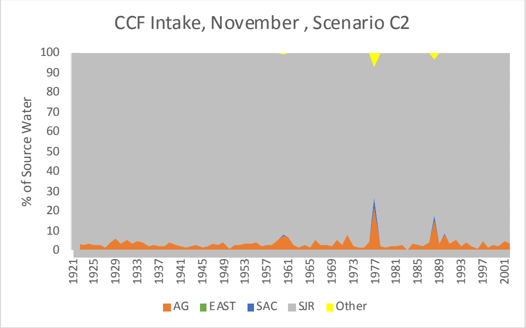
Figure 26 CHSWP003: CCF Intake

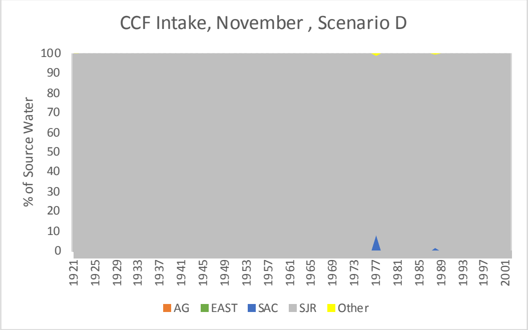


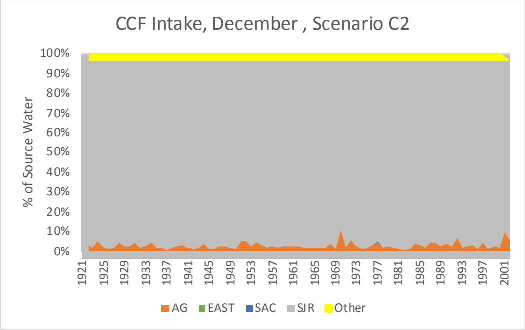












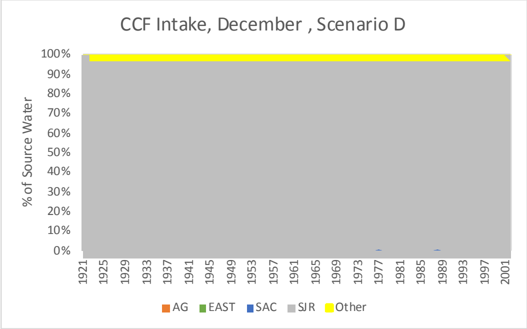


Figure 27 CHSWP003: CCF Intake

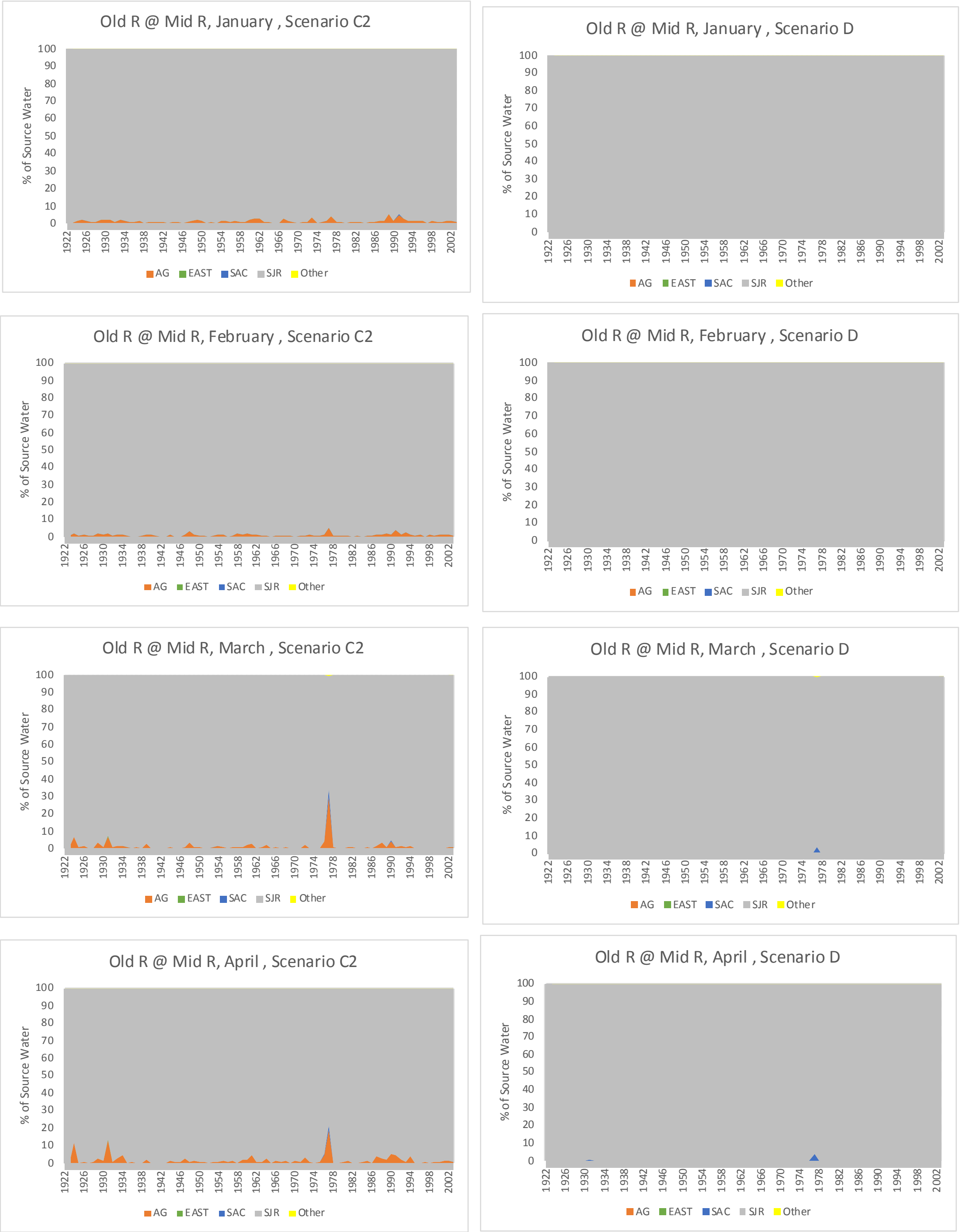


Figure 28 Oldr midr: Old River at Middle River

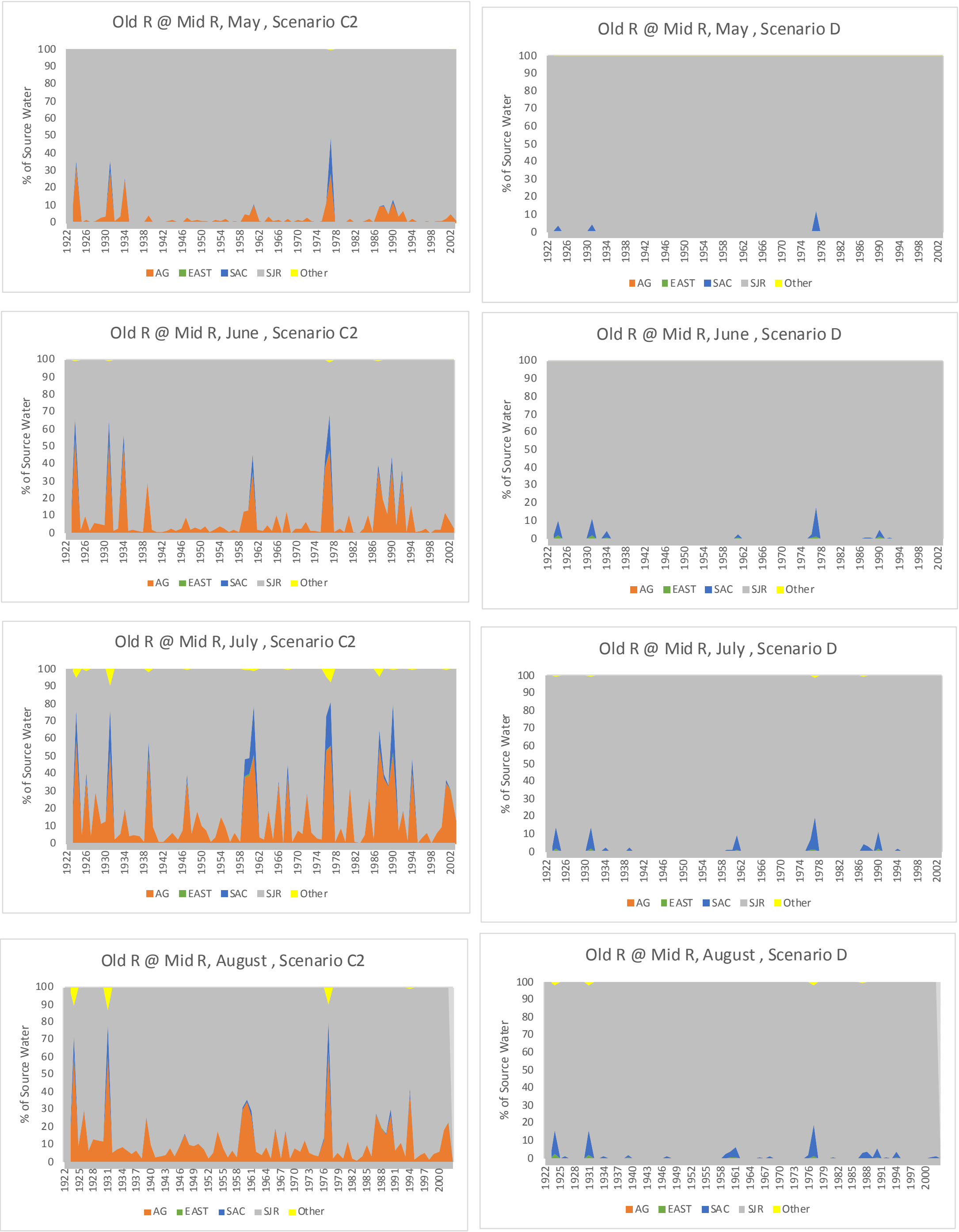


Figure 29 *Oldr midr: Old River at Middle River*

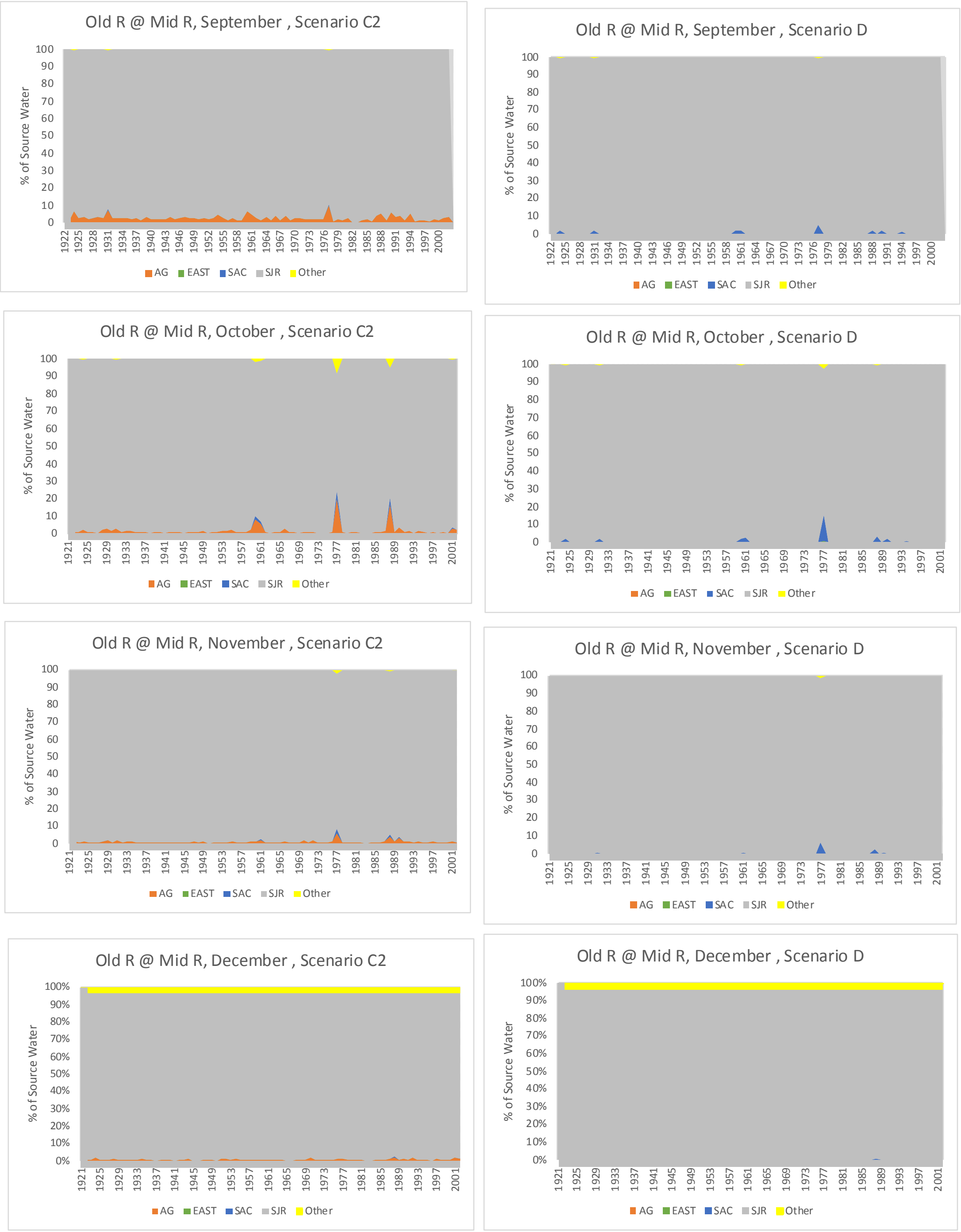


Figure 30 *Oldr midr: Old River at Middle River*

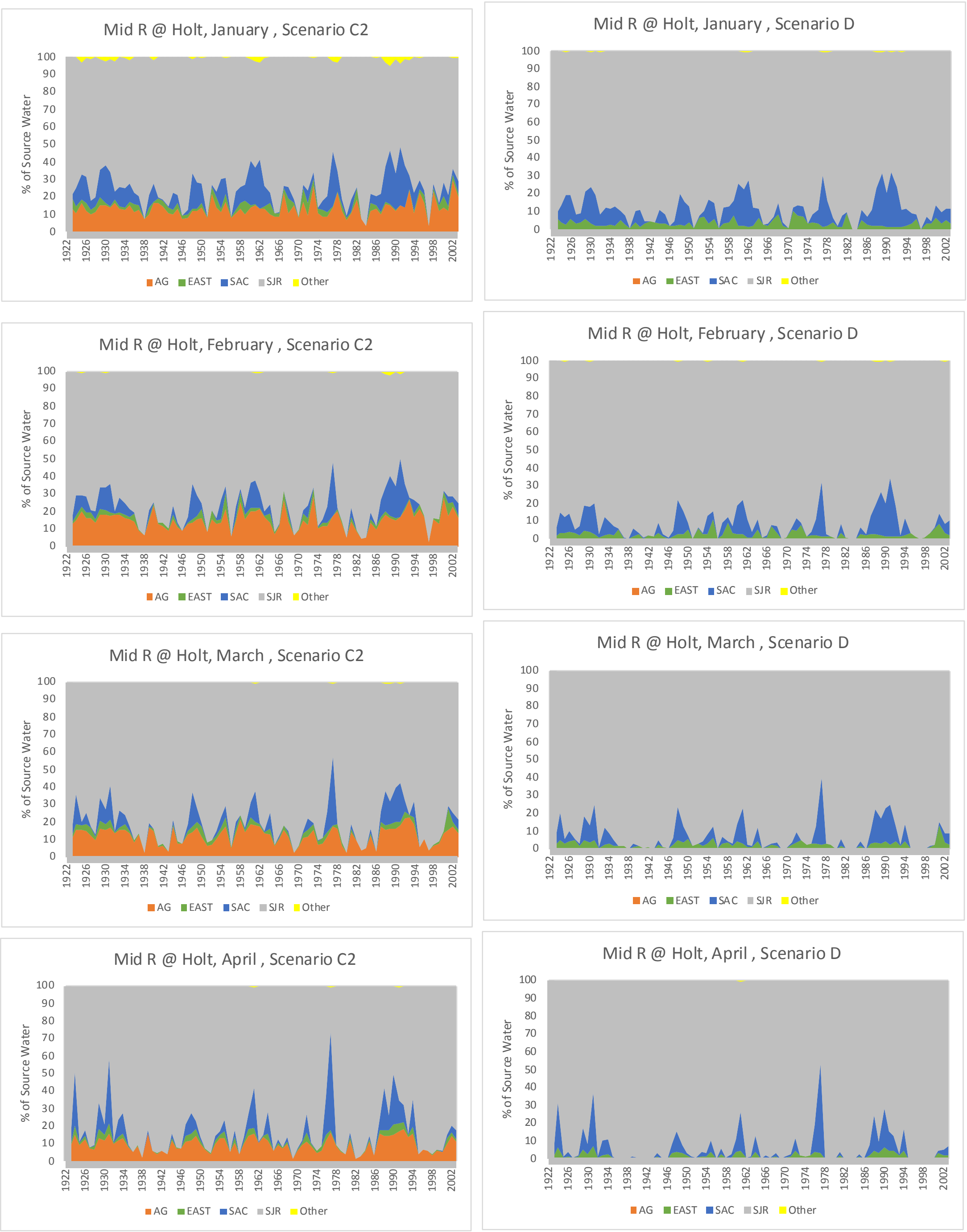


Figure 31 Rmid005: Middle River @ Holt

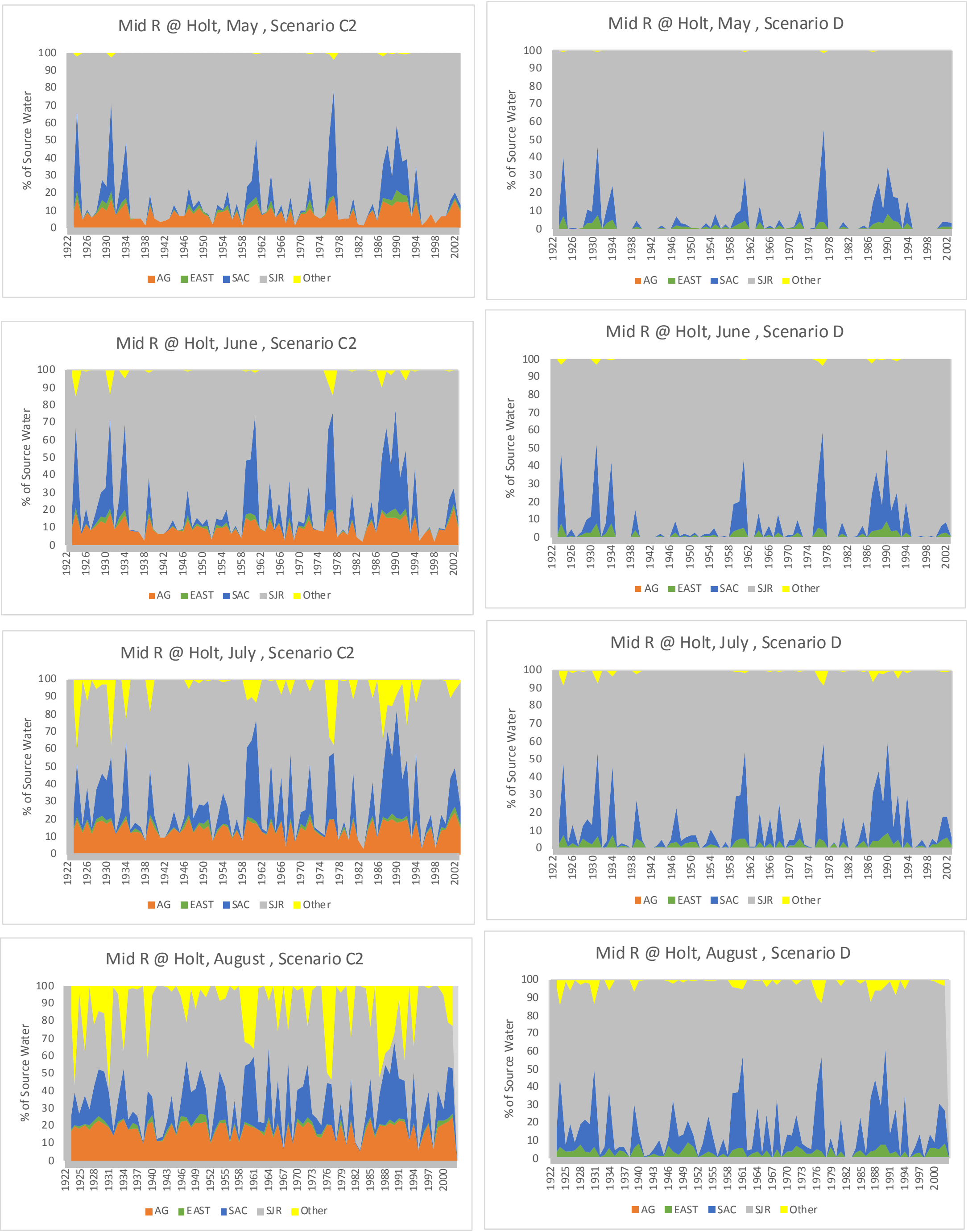


Figure 32 *Rmid005: Middle River @ Holt*

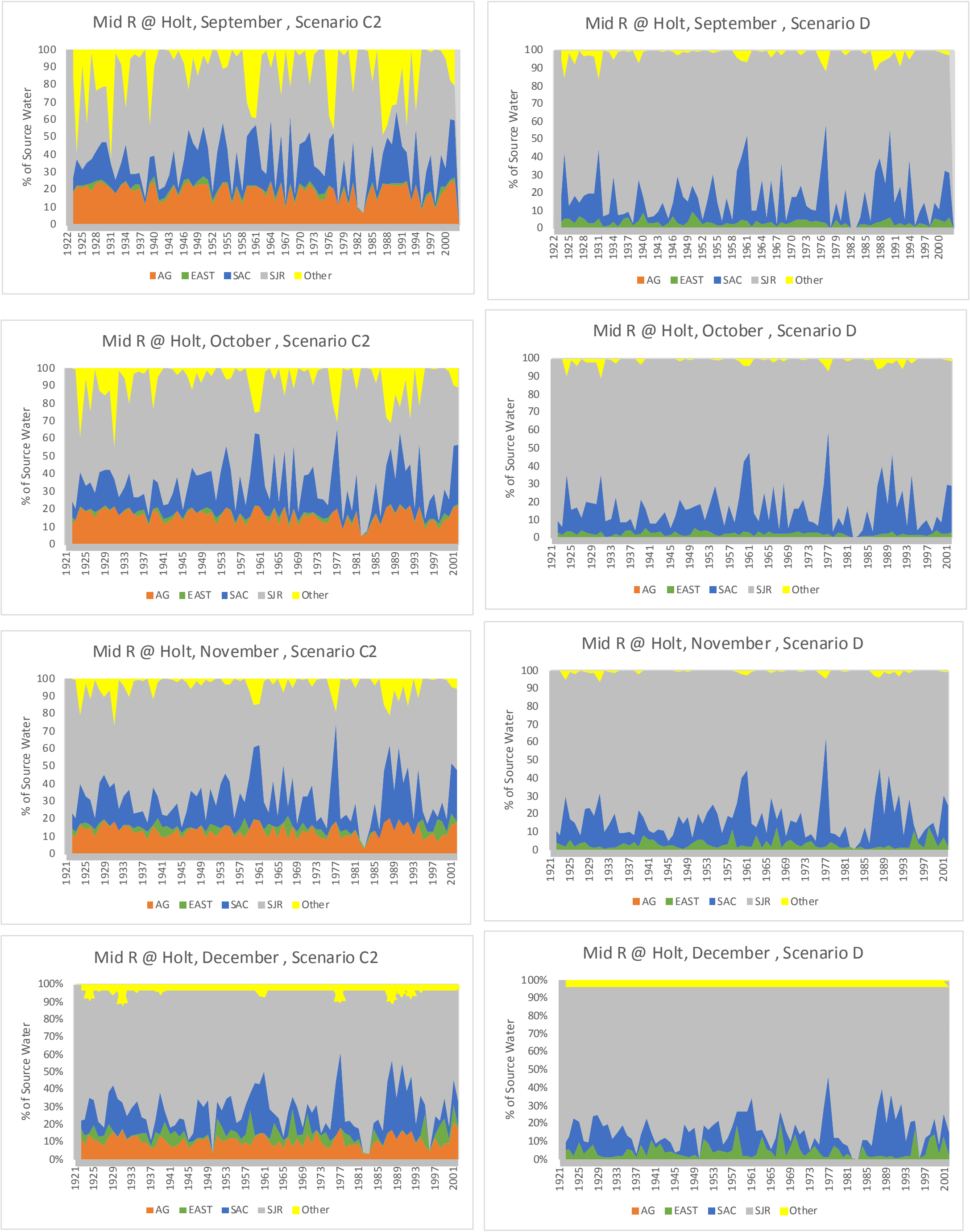


Figure 33 *Rmid005: Middle River @ Holt*

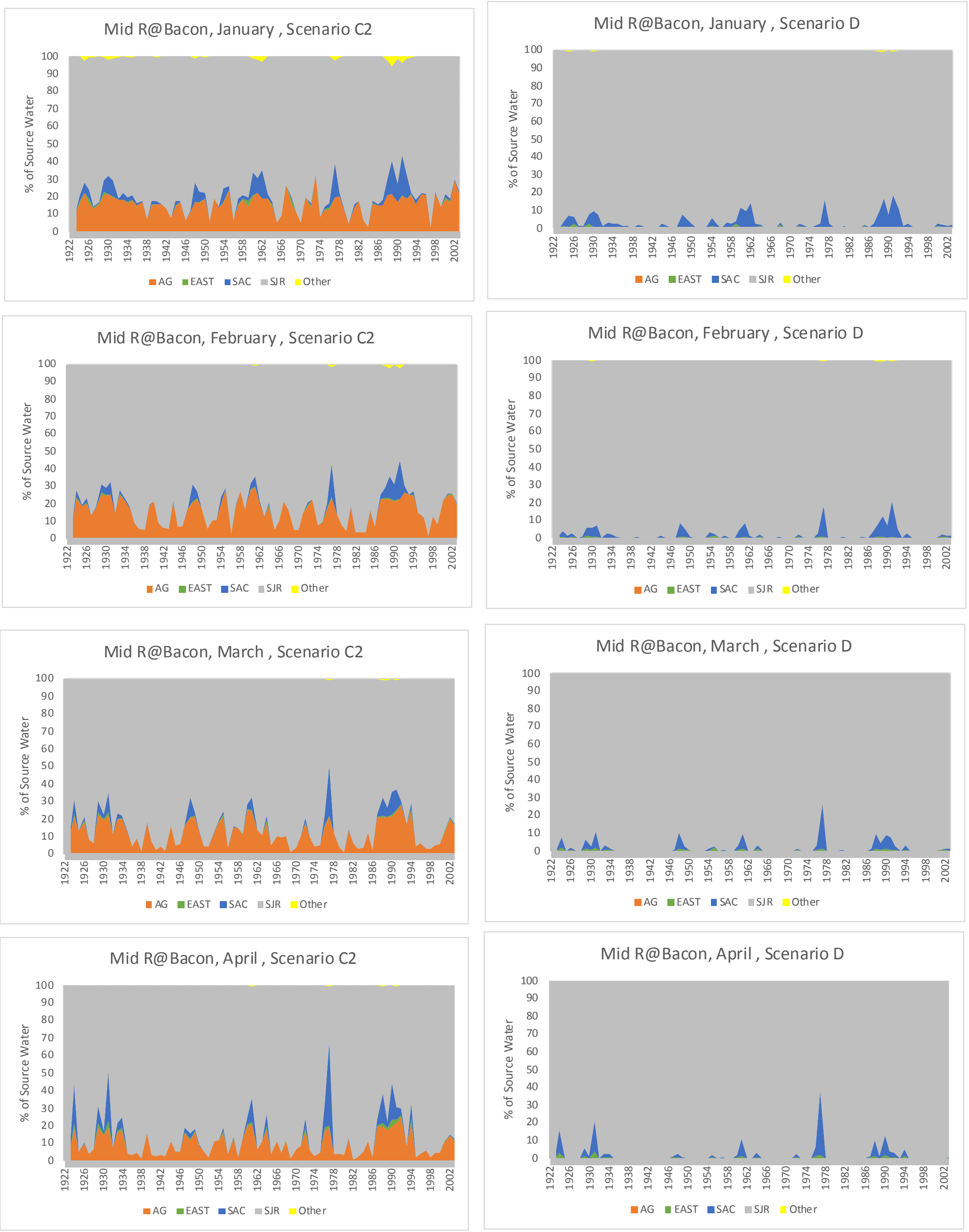


Figure 34 Rmid015: Middle River @ Bacon Island

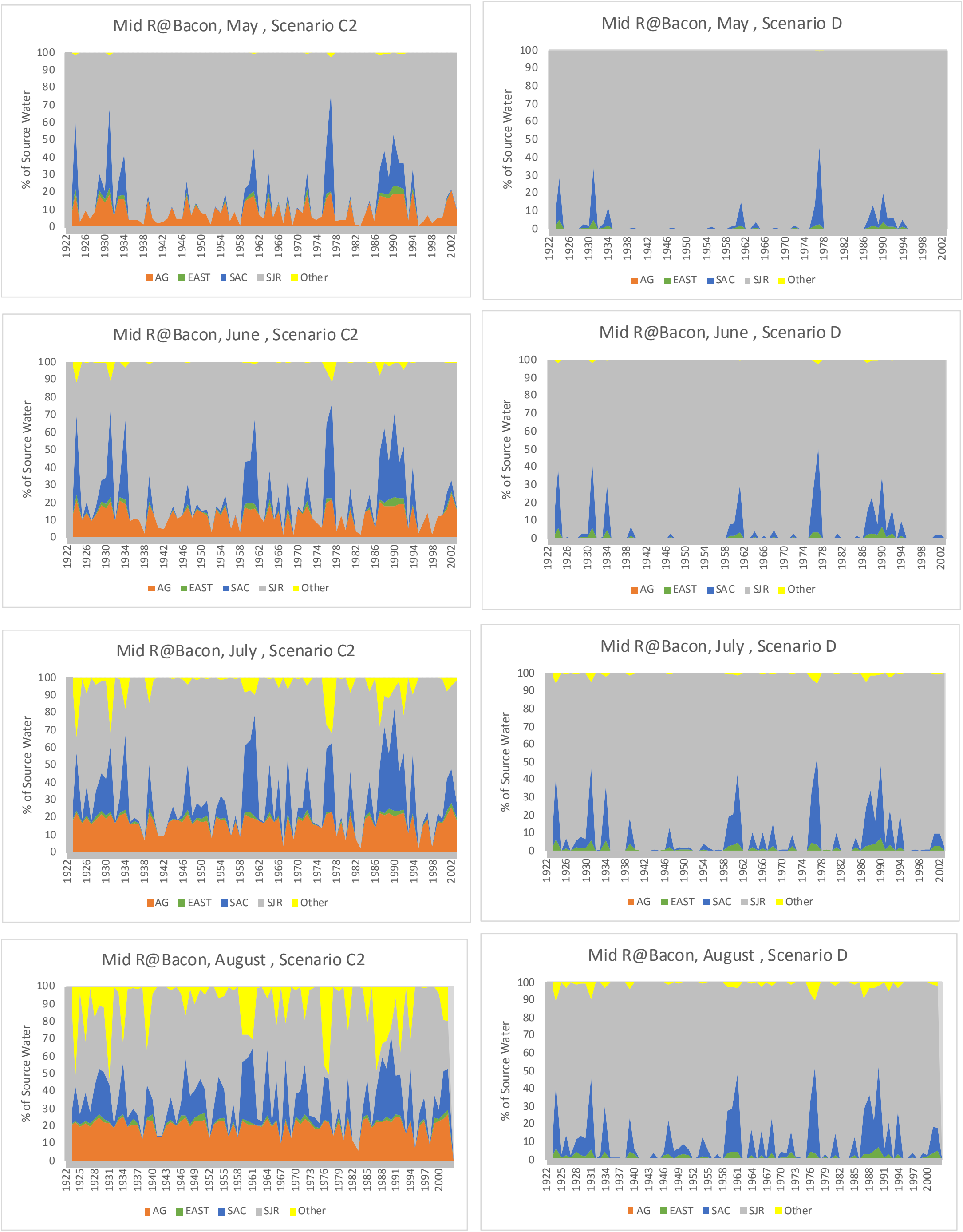


Figure 35 Rmid015: Middle River @ Bacon Island

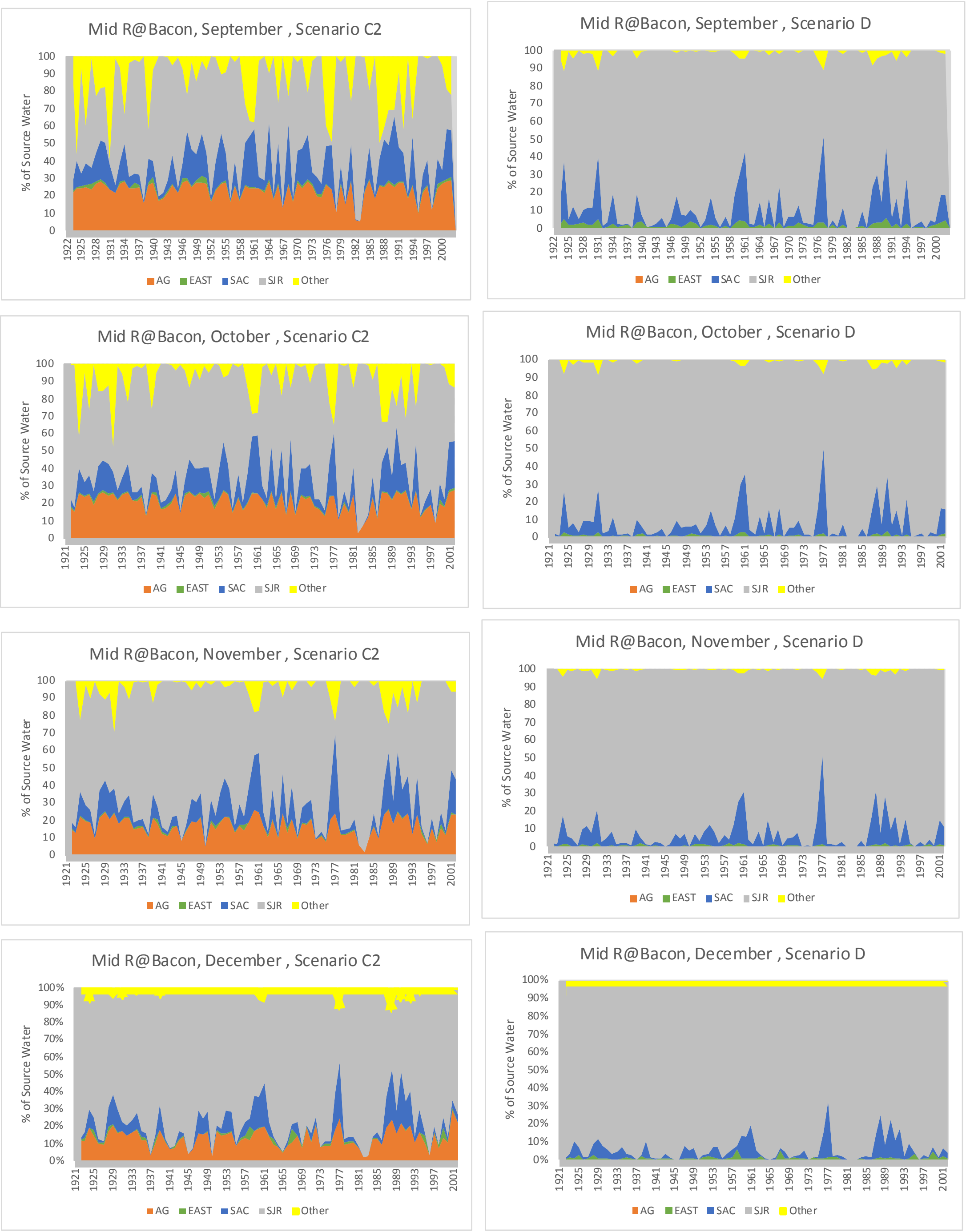


Figure 36 Rmid015: Middle River @ Bacon Island

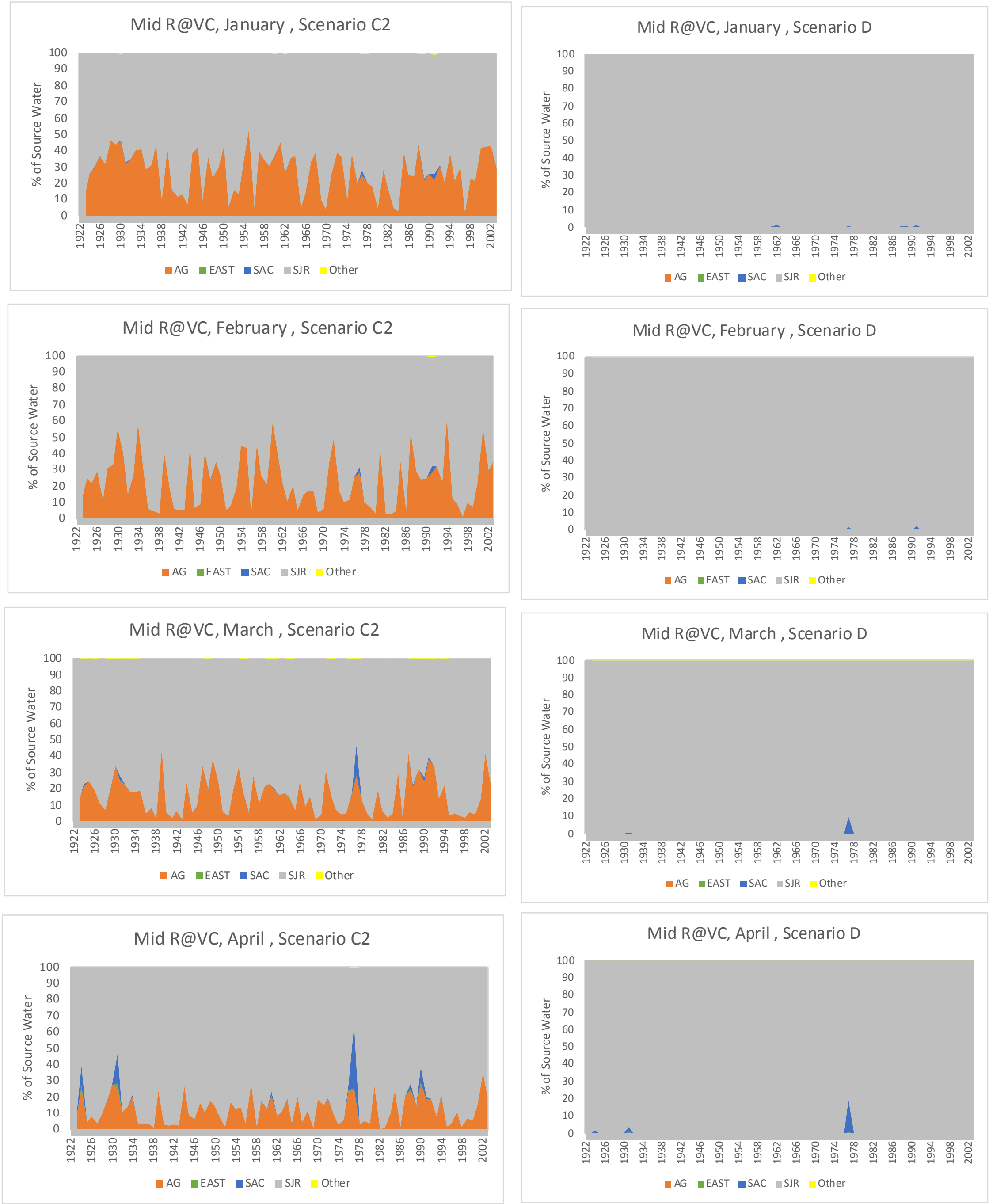


Figure 37 *Rmid027: Middle River @ Victoria Canal*

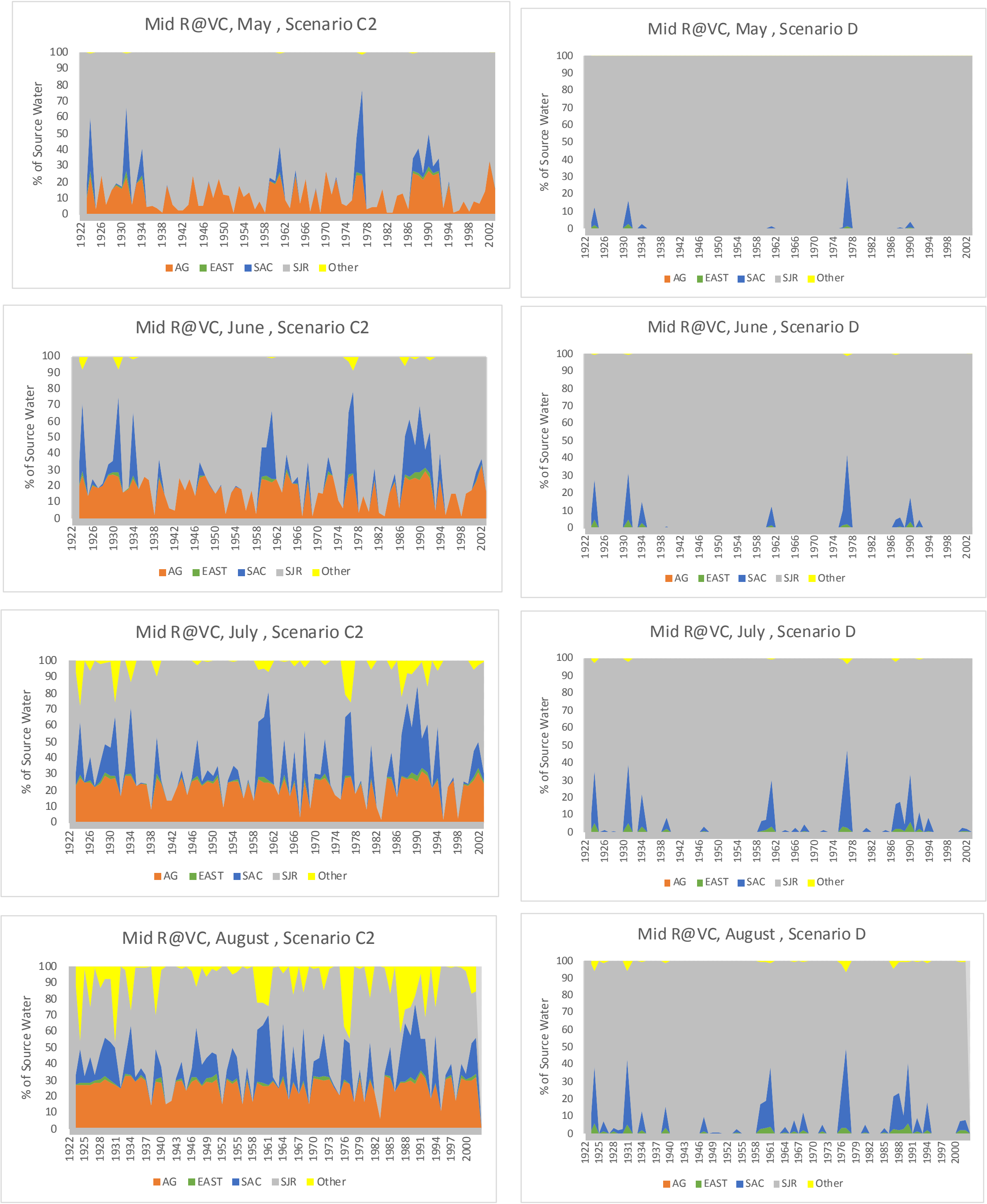


Figure 38 Rmid027: Middle River @ Victoria Canal

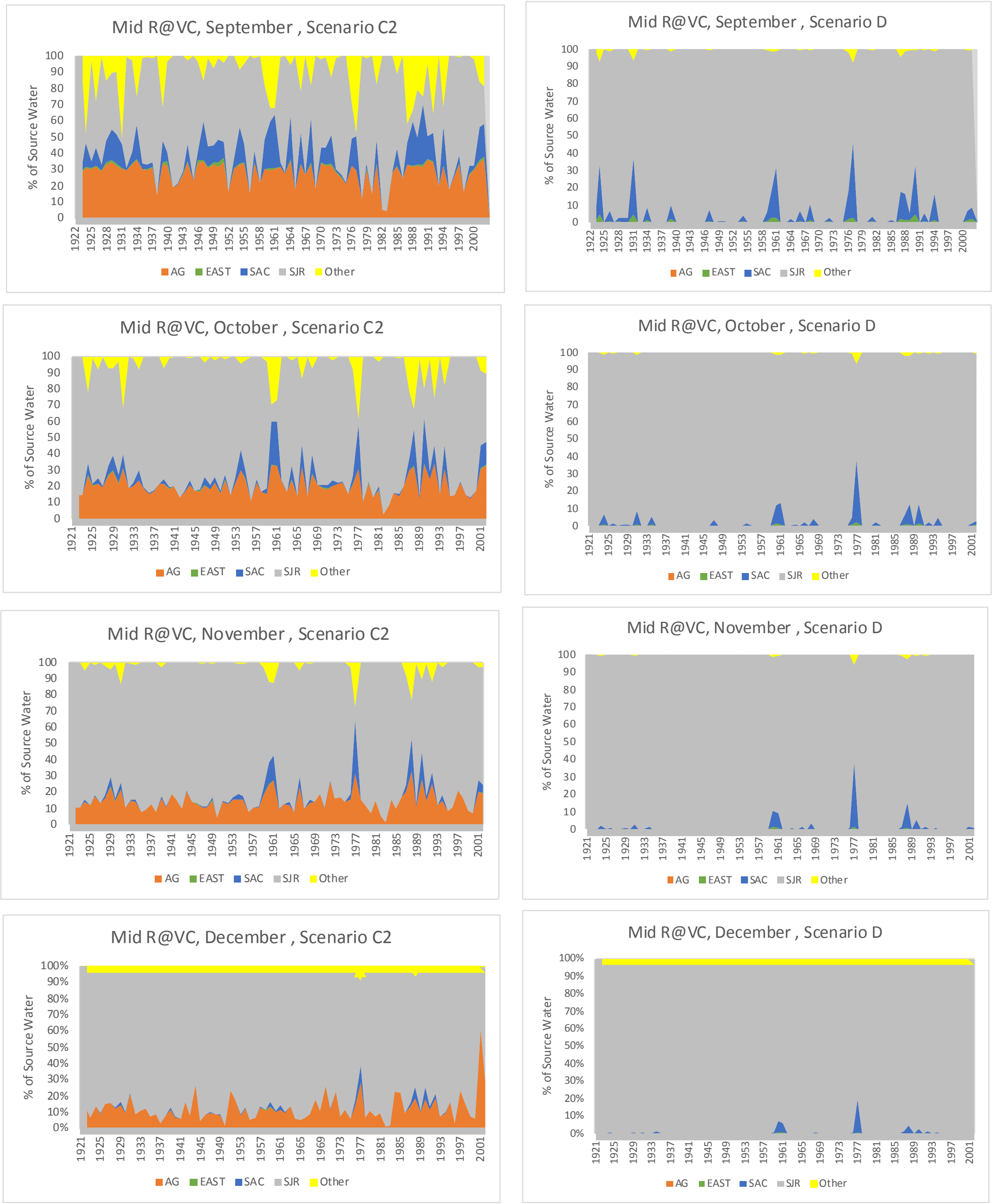


Figure 39 *Rmid027: Middle River @ Victoria Canal*

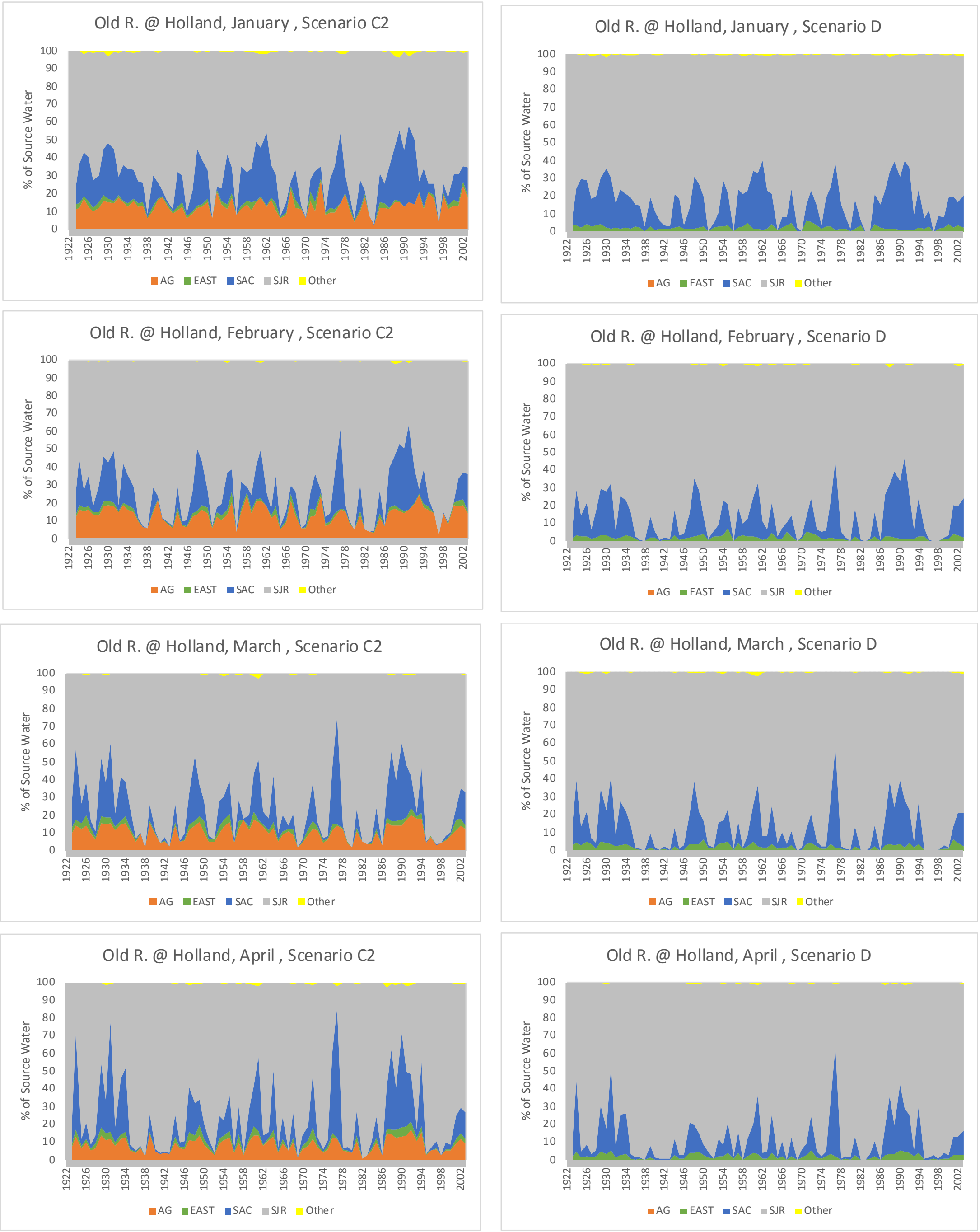


Figure 40 Rold014: Old River @ Holland

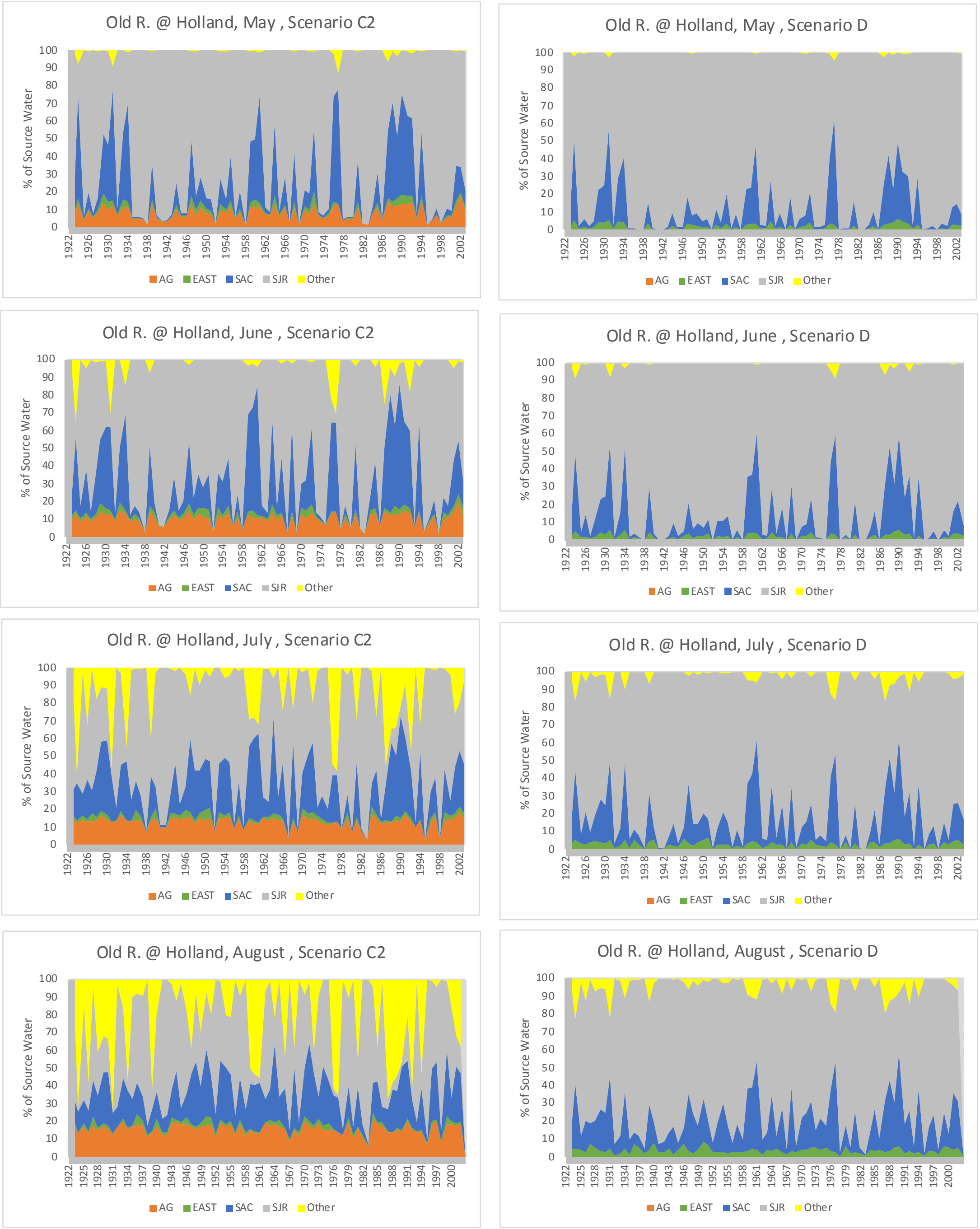


Figure 41 *Rold014: Old River @ Holland*

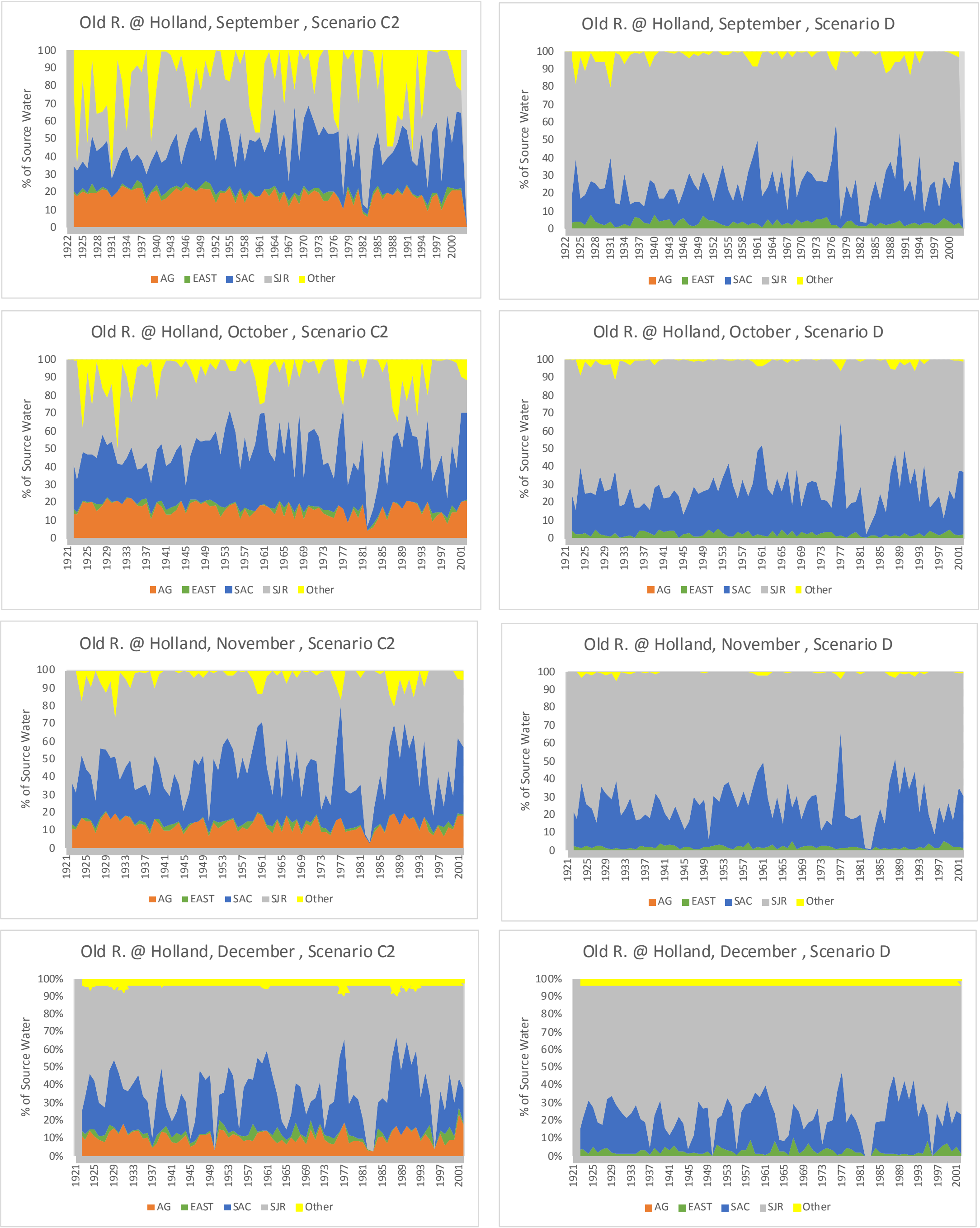


Figure 42 Rold014: Old River @ Holland

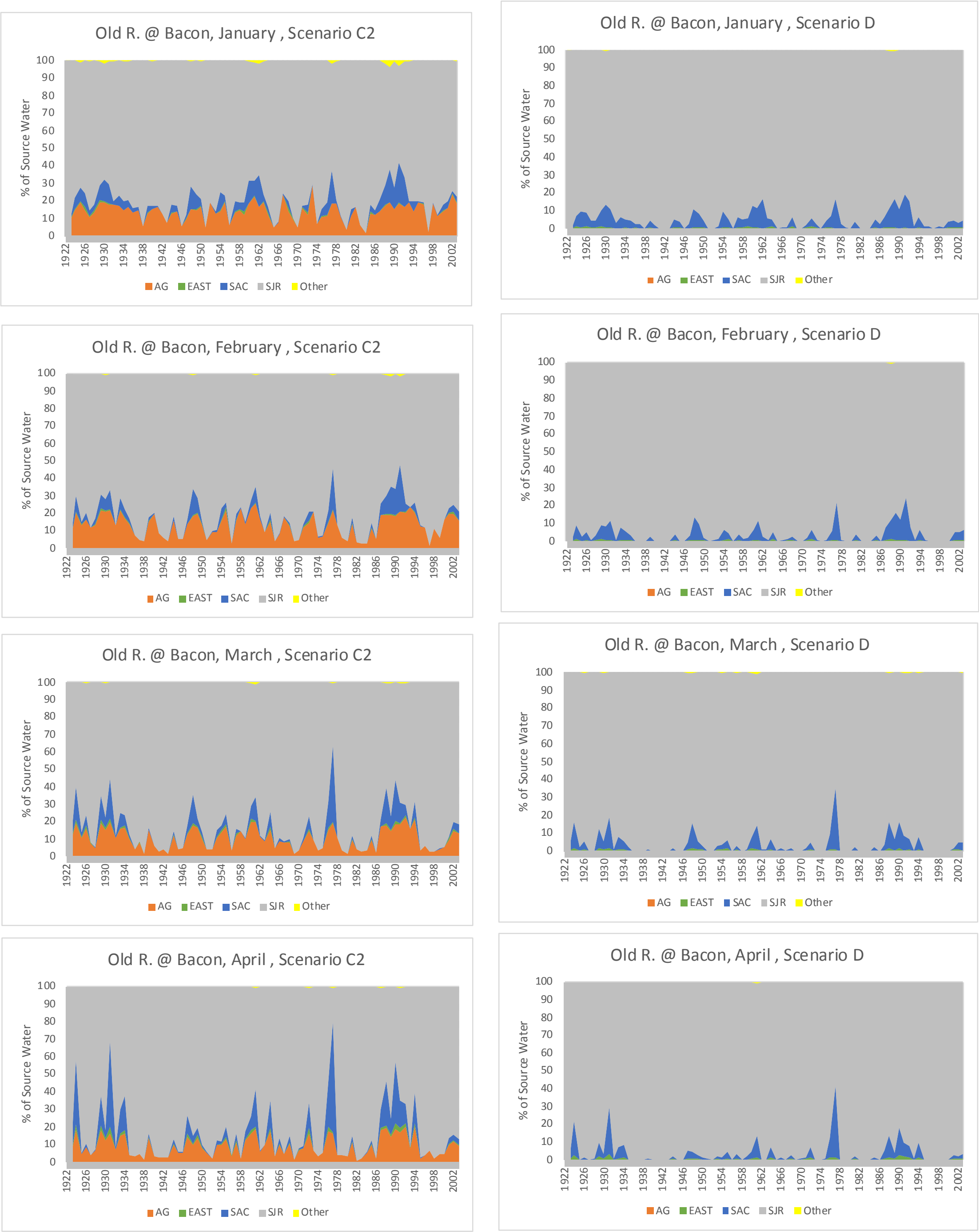


Figure 43 Rold024: Old River @ Bacon Island

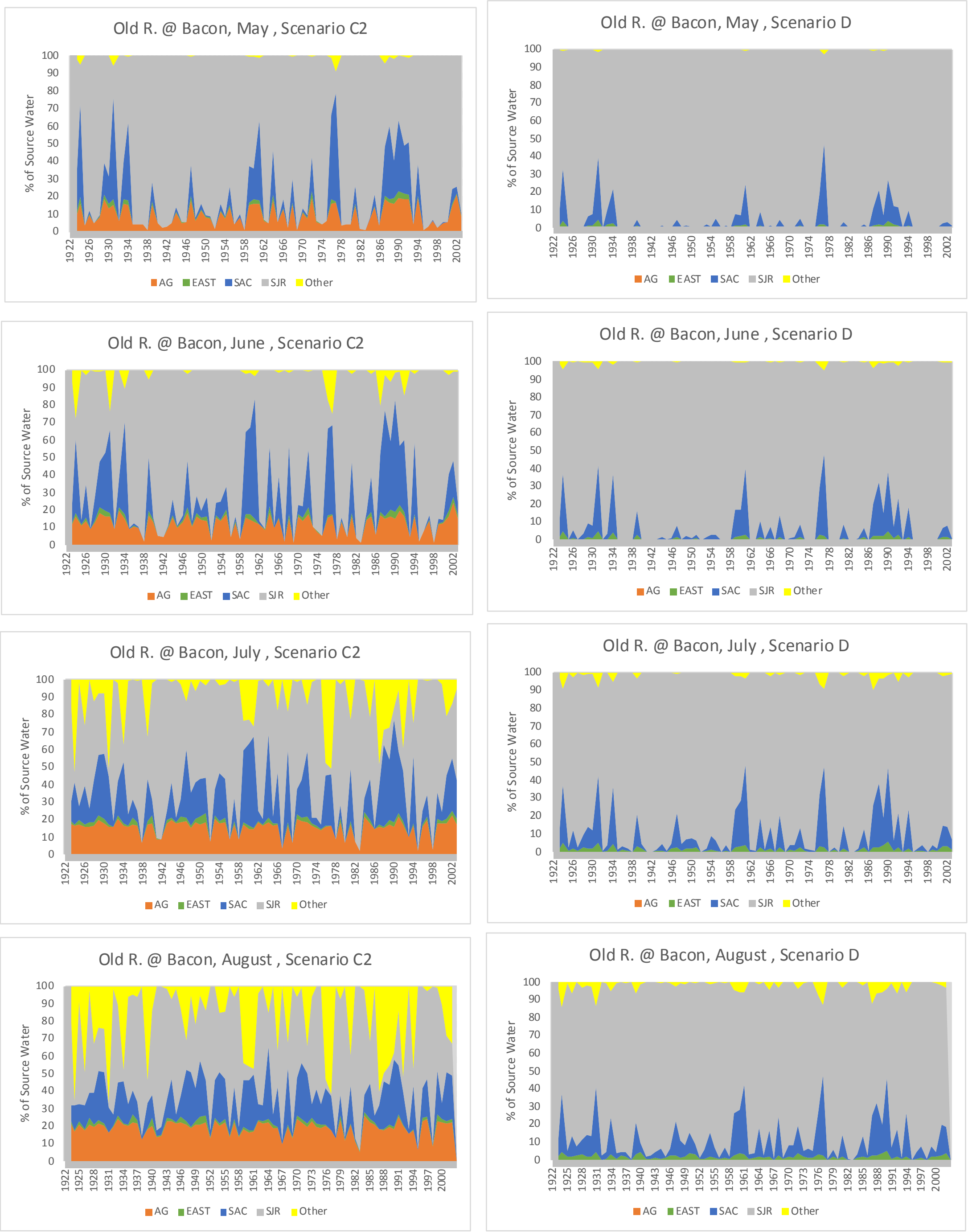


Figure 44 *Rold024: Old River @ Bacon Island*

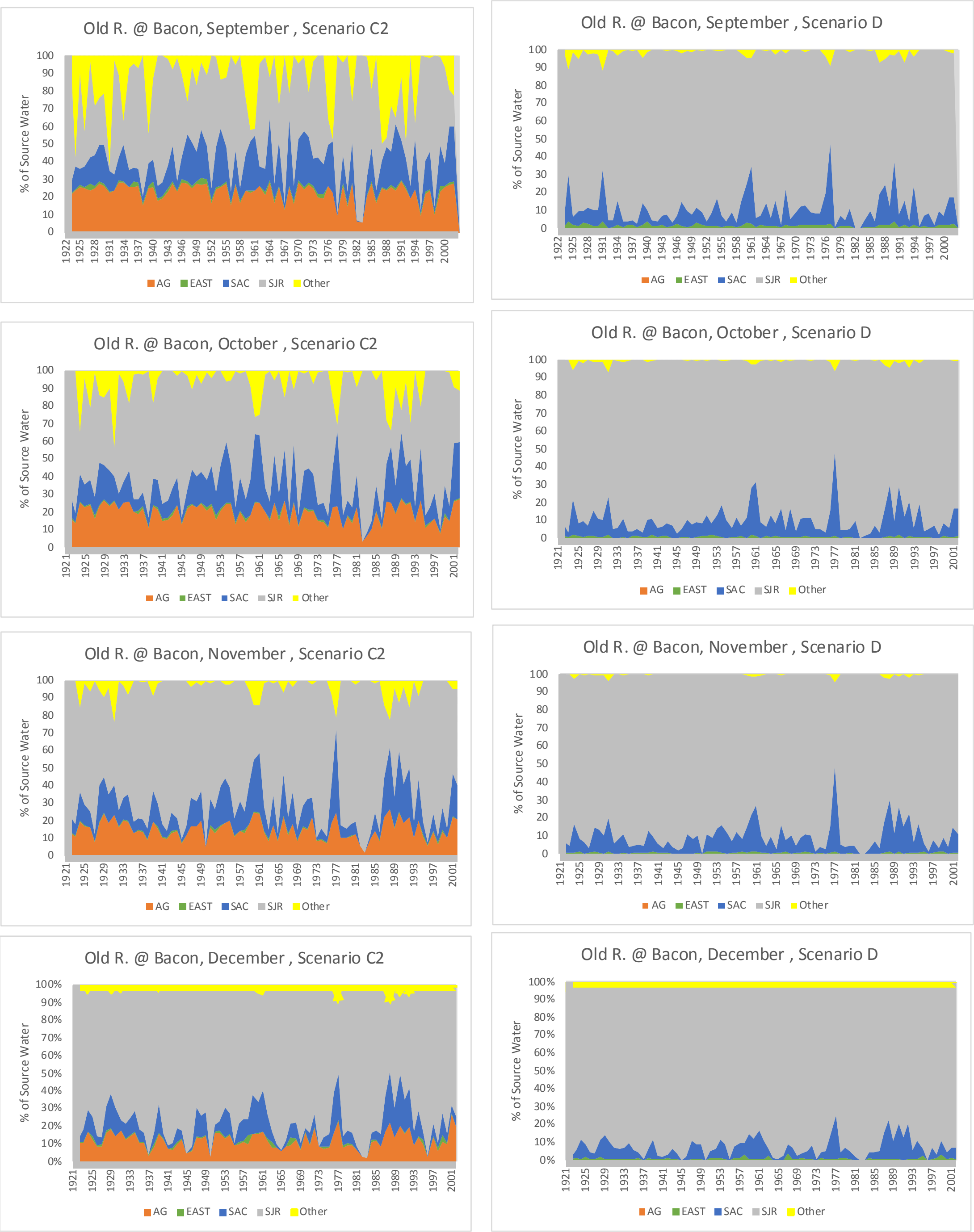


Figure 45 Rold024: Old River @ Bacon Island

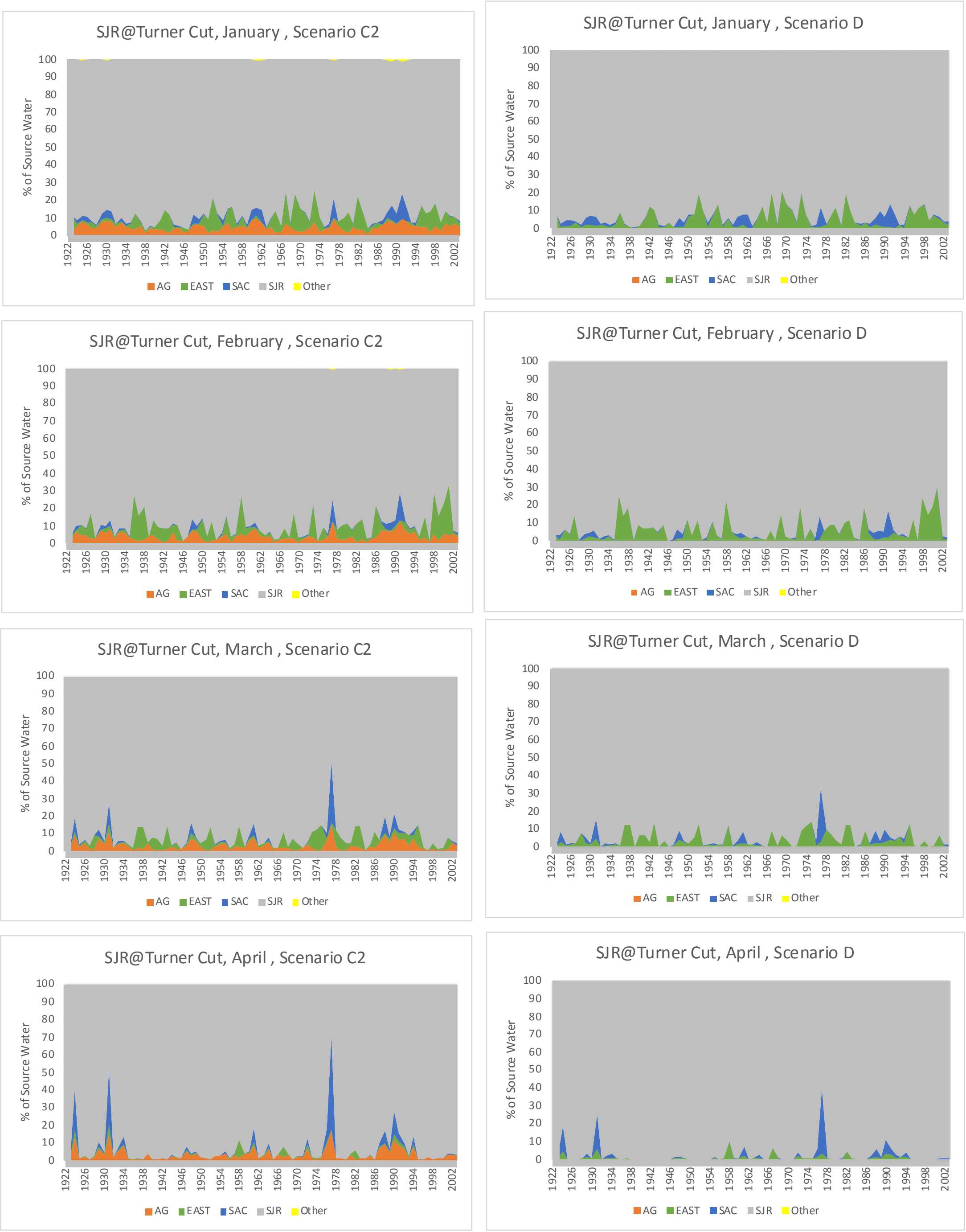


Figure 46 RSAN046: SJR @ Turner Cut

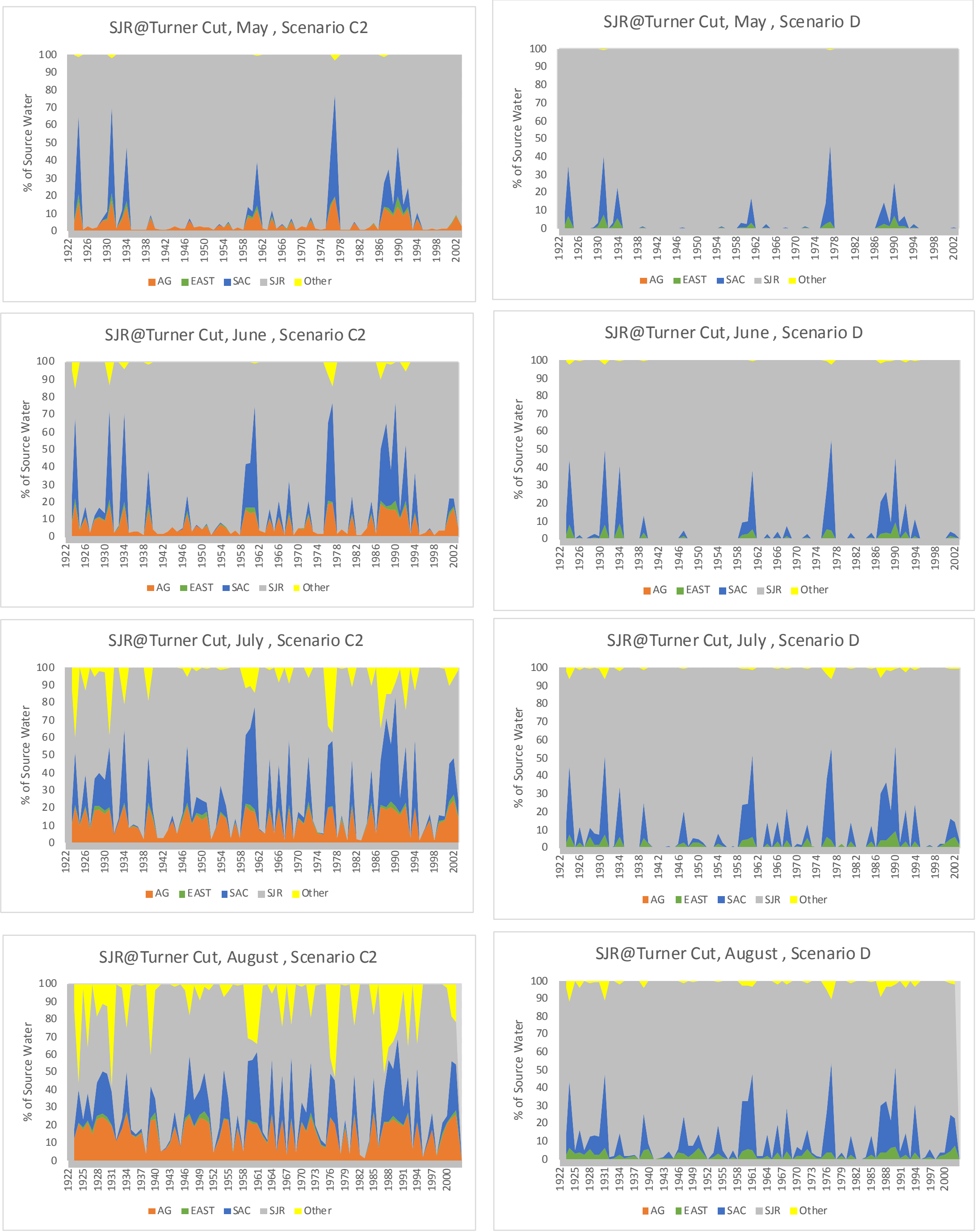


Figure 47 *RSAN046: SJR @ Turner Cut*

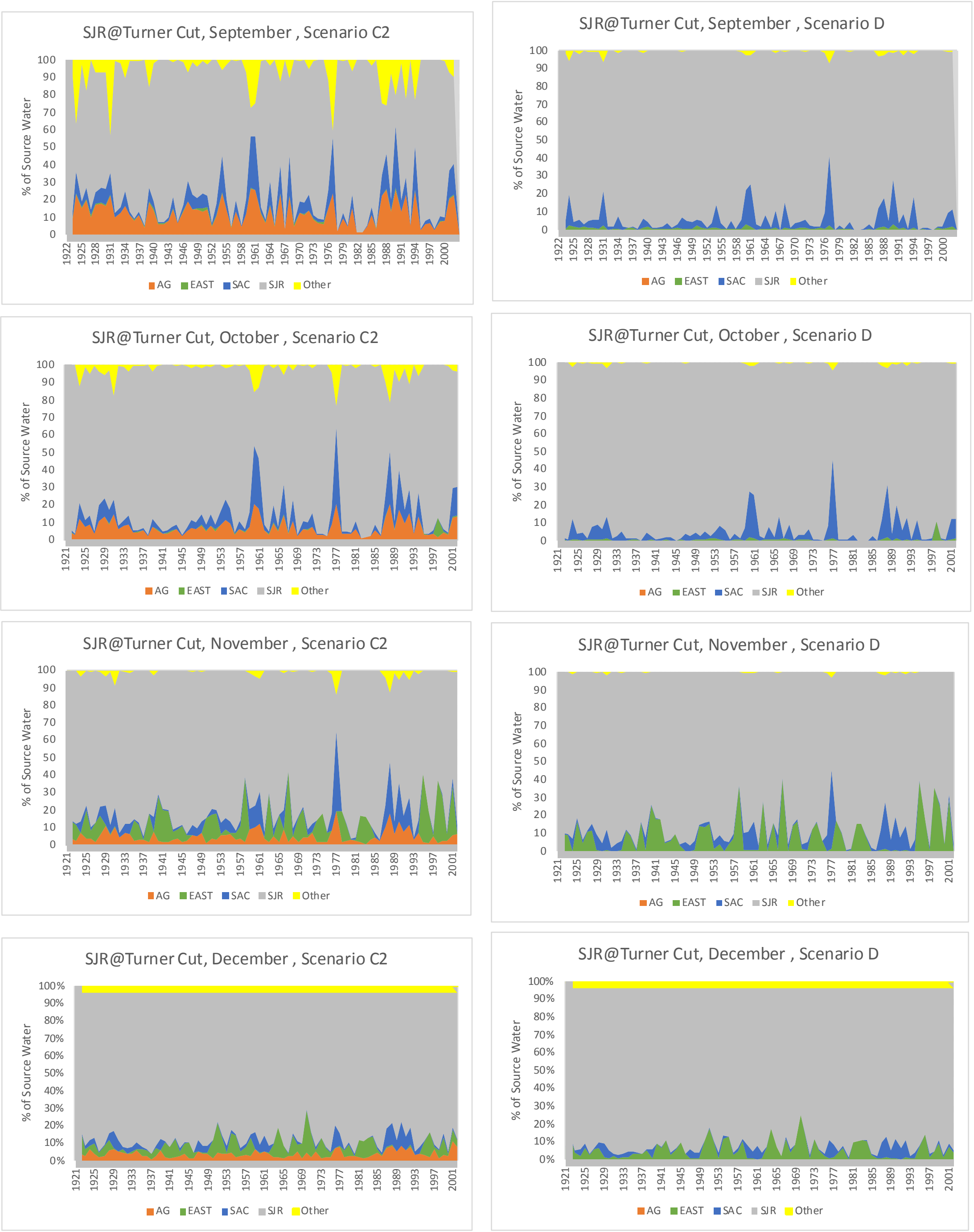


Figure 48 RSAN046: SJR @ Turner Cut

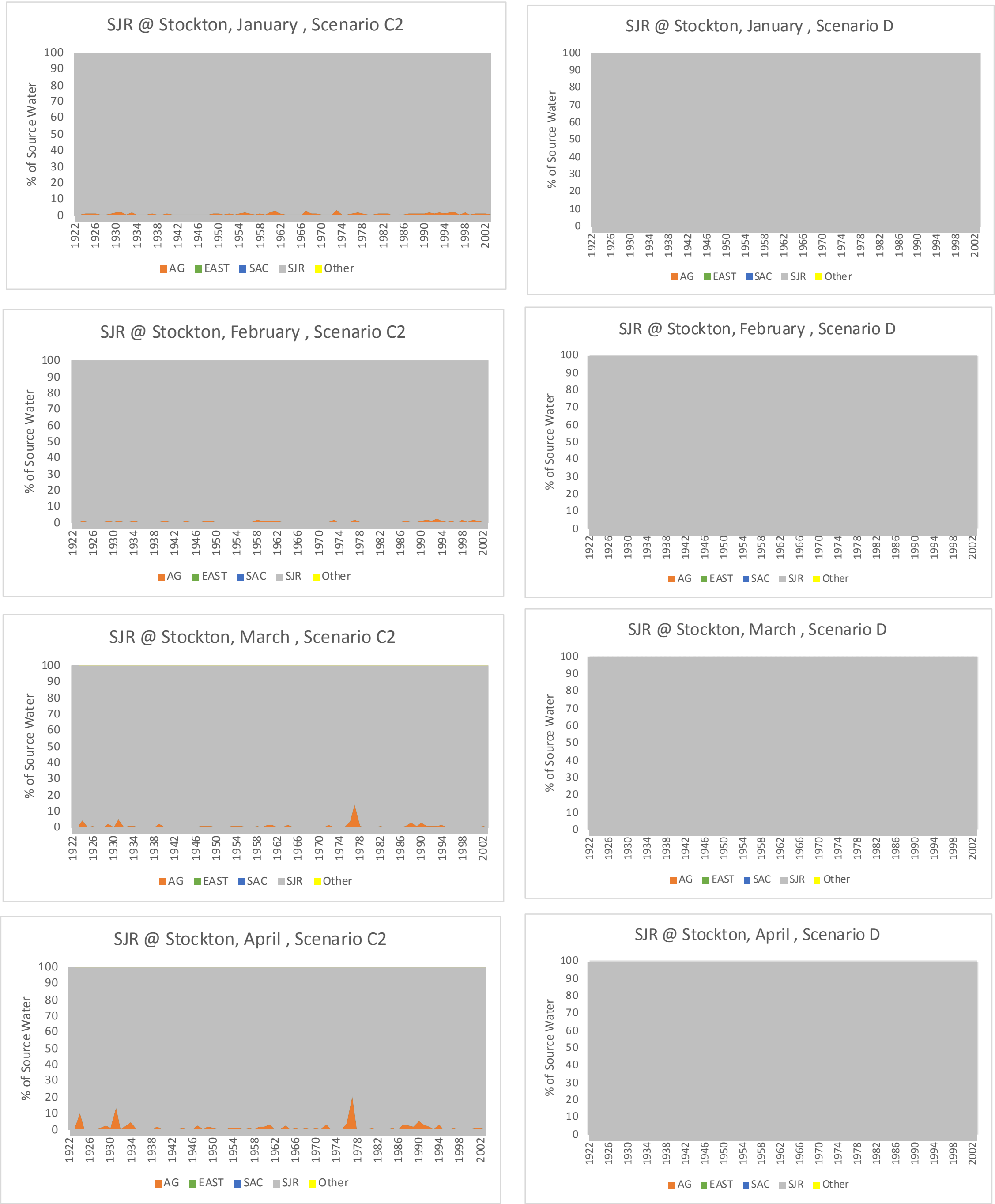


Figure 49 RSAN063: SJR @ Stockton

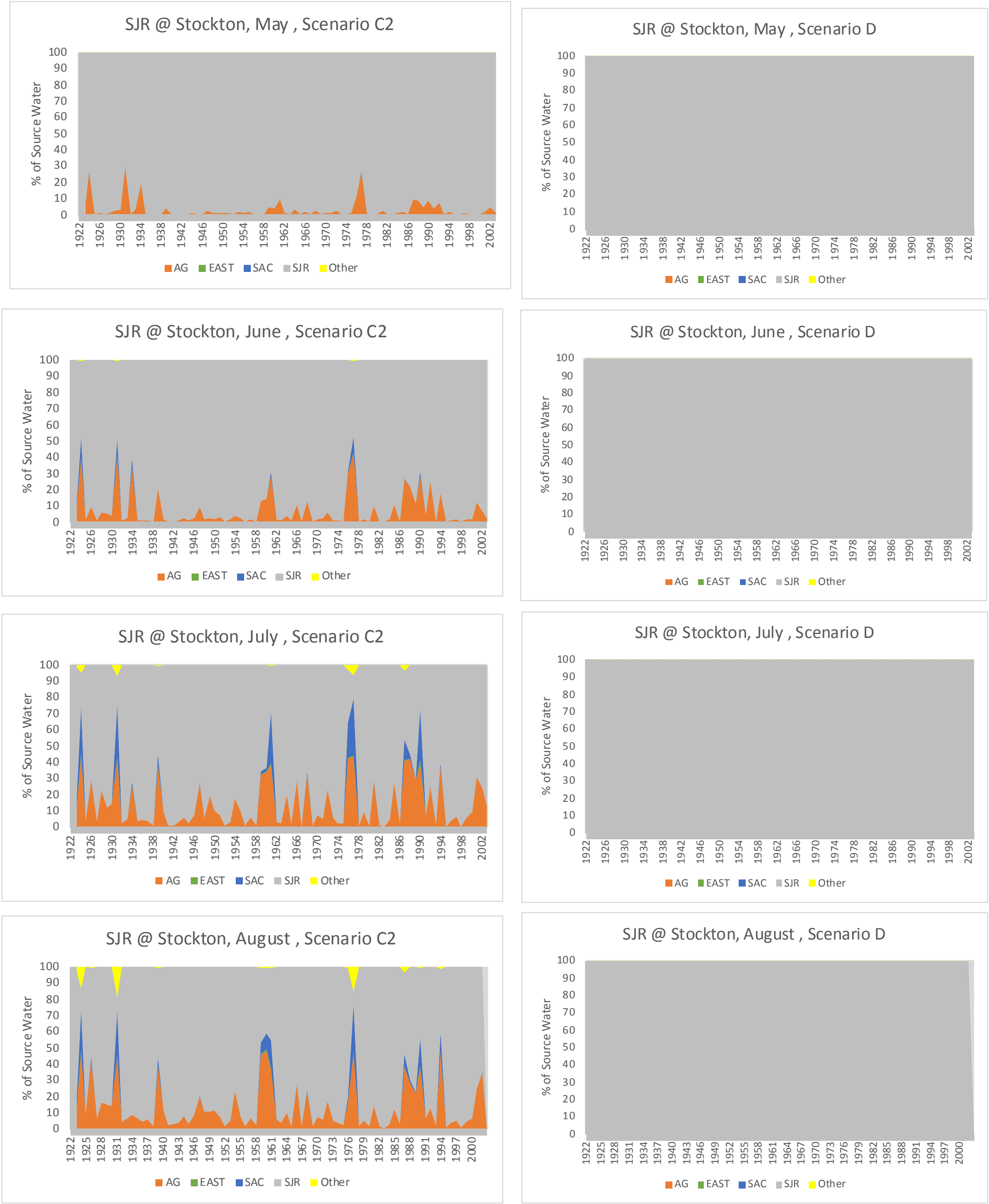


Figure 50 RSAN063: SJR @ Stockton

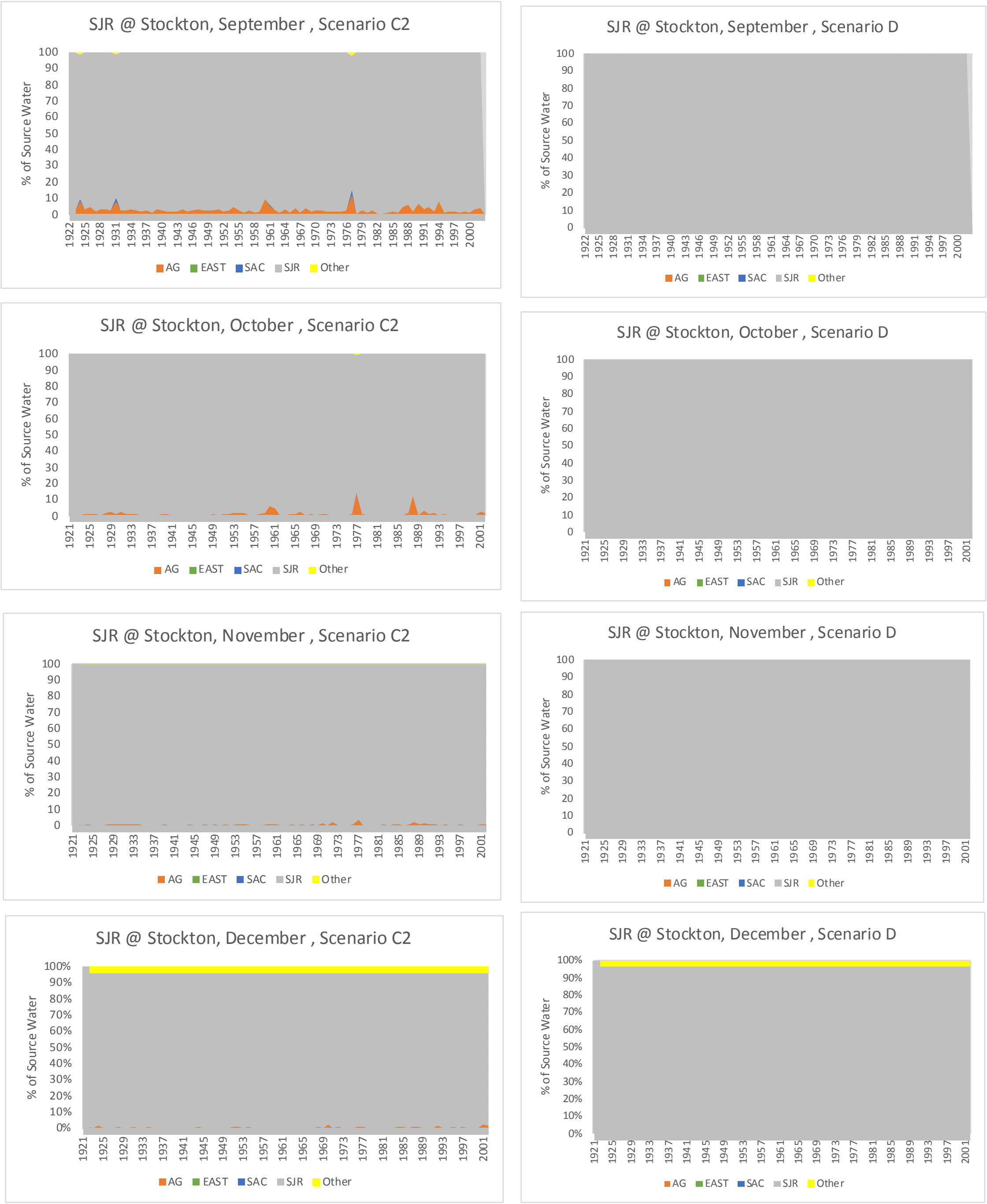


Figure 51 RSAN063: SJR @ Stockton

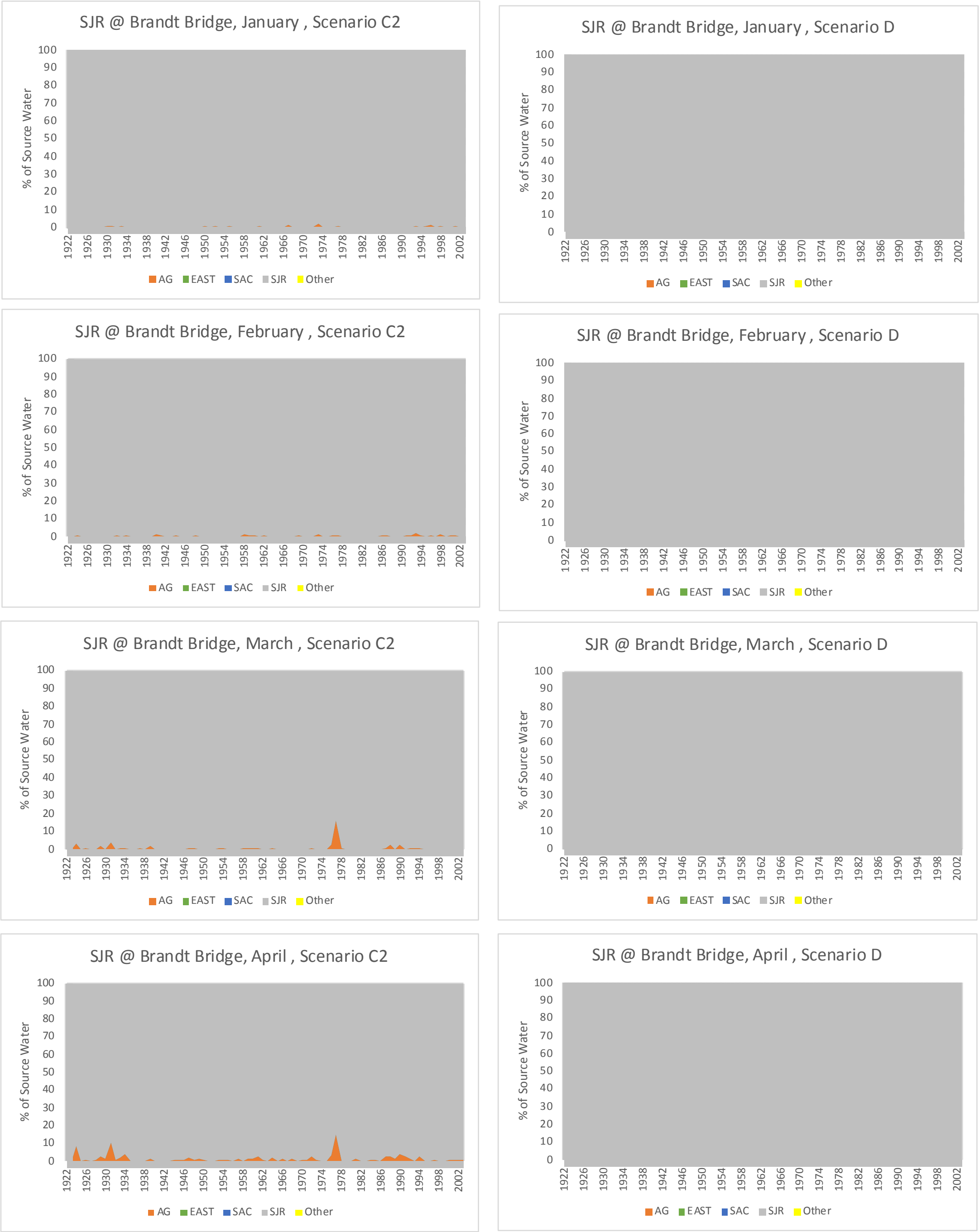


Figure 52 RSAN072: SJR @ Brandt Bridge

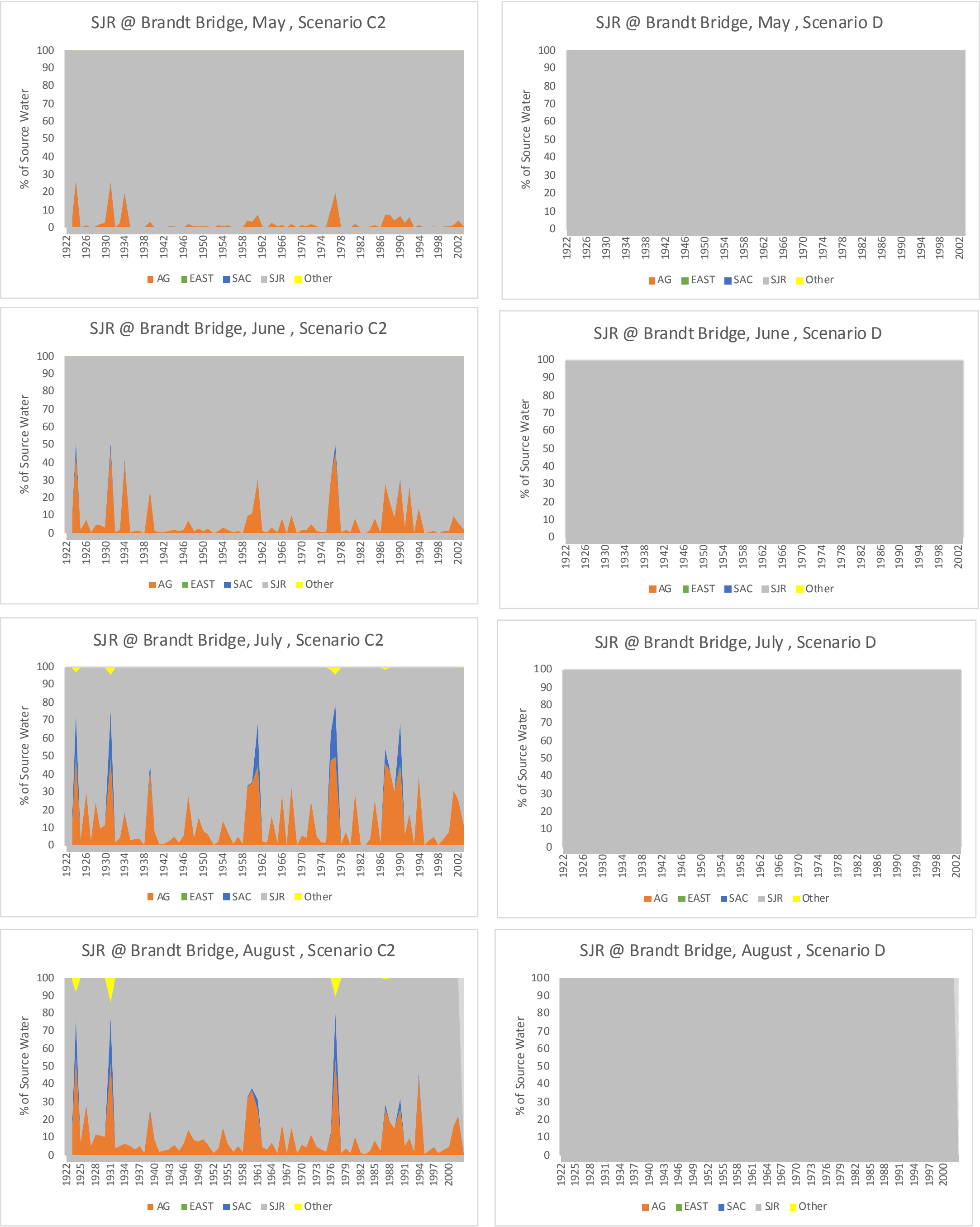
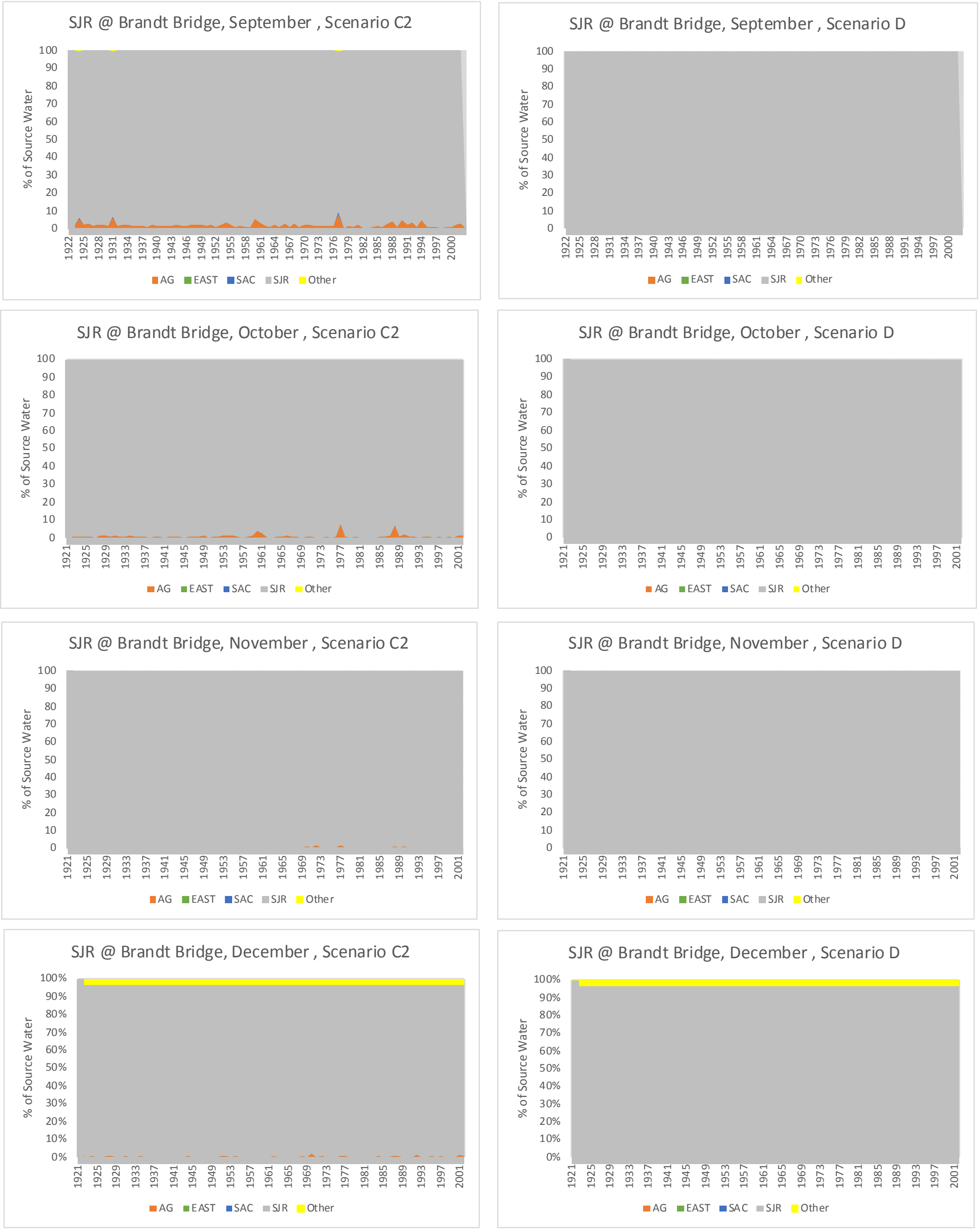


Figure 53 *RSAN072: SJR @ Brandt Bridge*



SJR @ Brandt Bridge, September , Scenario C2

SJR @ Brandt Bridge, September , Scenario D

SJR @ Brandt Bridge, October , Scenario C2

SJR @ Brandt Bridge, October , Scenario D

SJR @ Brandt Bridge, November , Scenario C2

SJR @ Brandt Bridge, November , Scenario D

SJR @ Brandt Bridge, December , Scenario C2

SJR @ Brandt Bridge, December , Scenario D

Figure 54 RSAN072: SJR @ Brandt Bridge

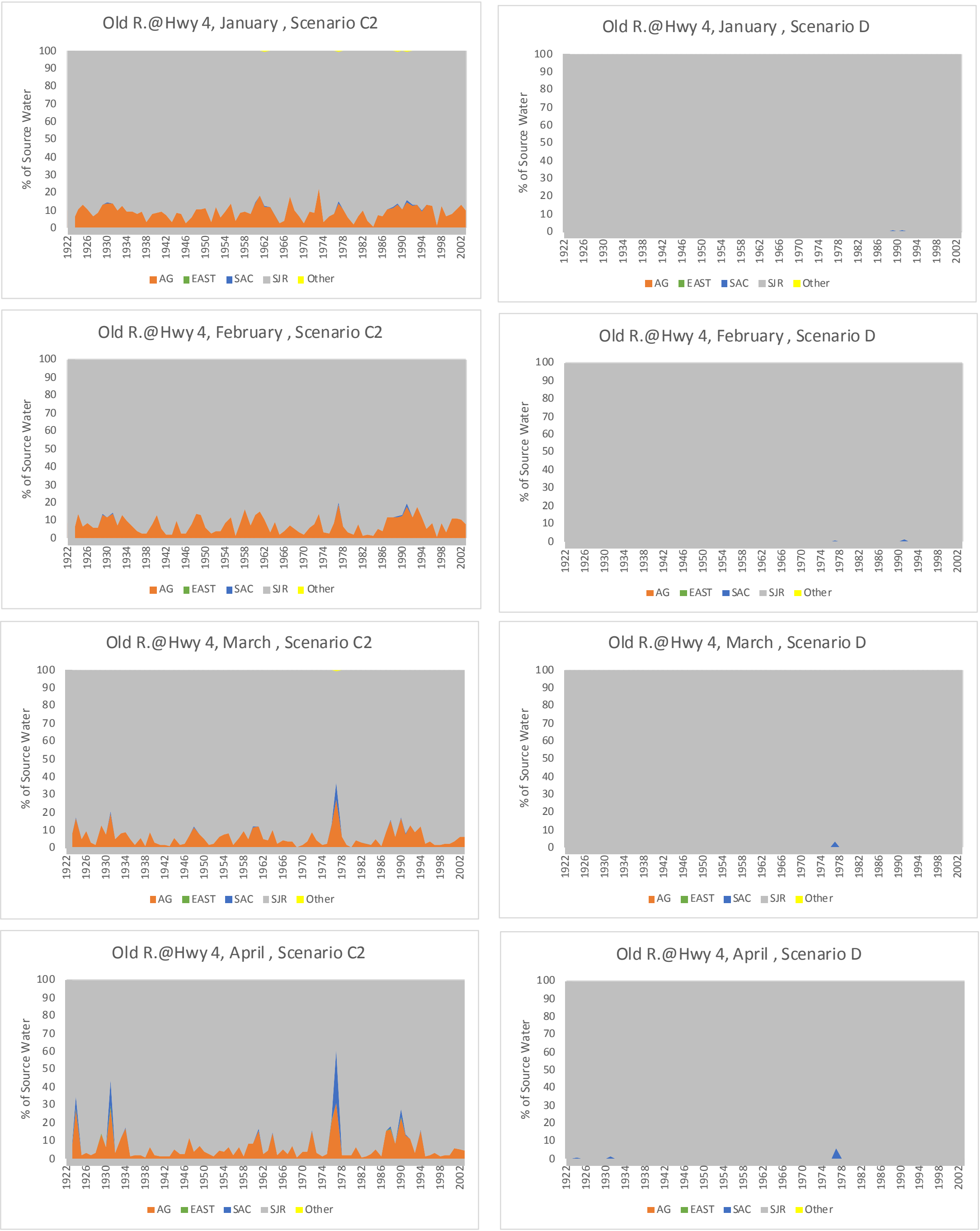


Figure 55 *Rold034: Old River @ Hwy 4*

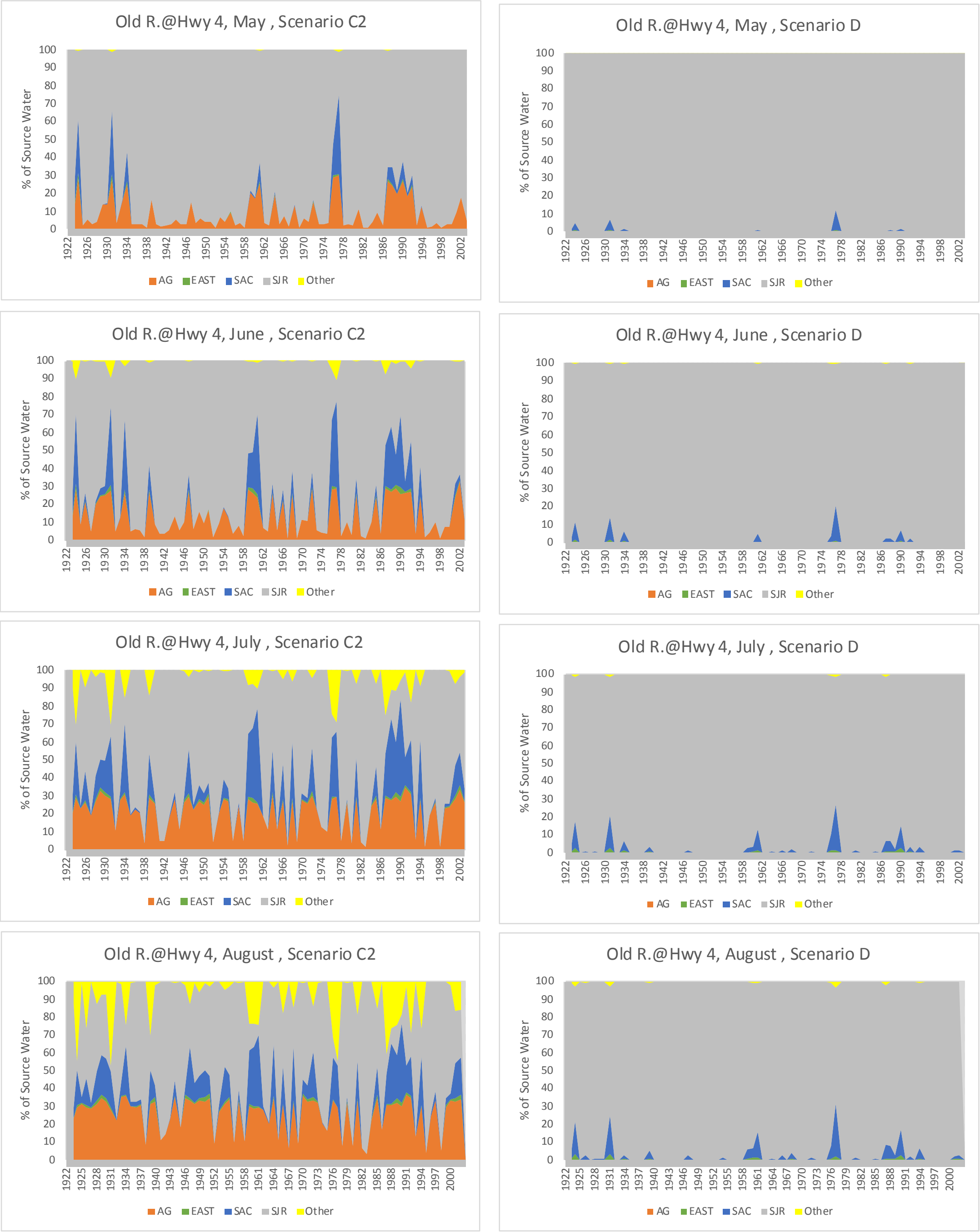


Figure 56 Rold034: Old River @ Hwy 4

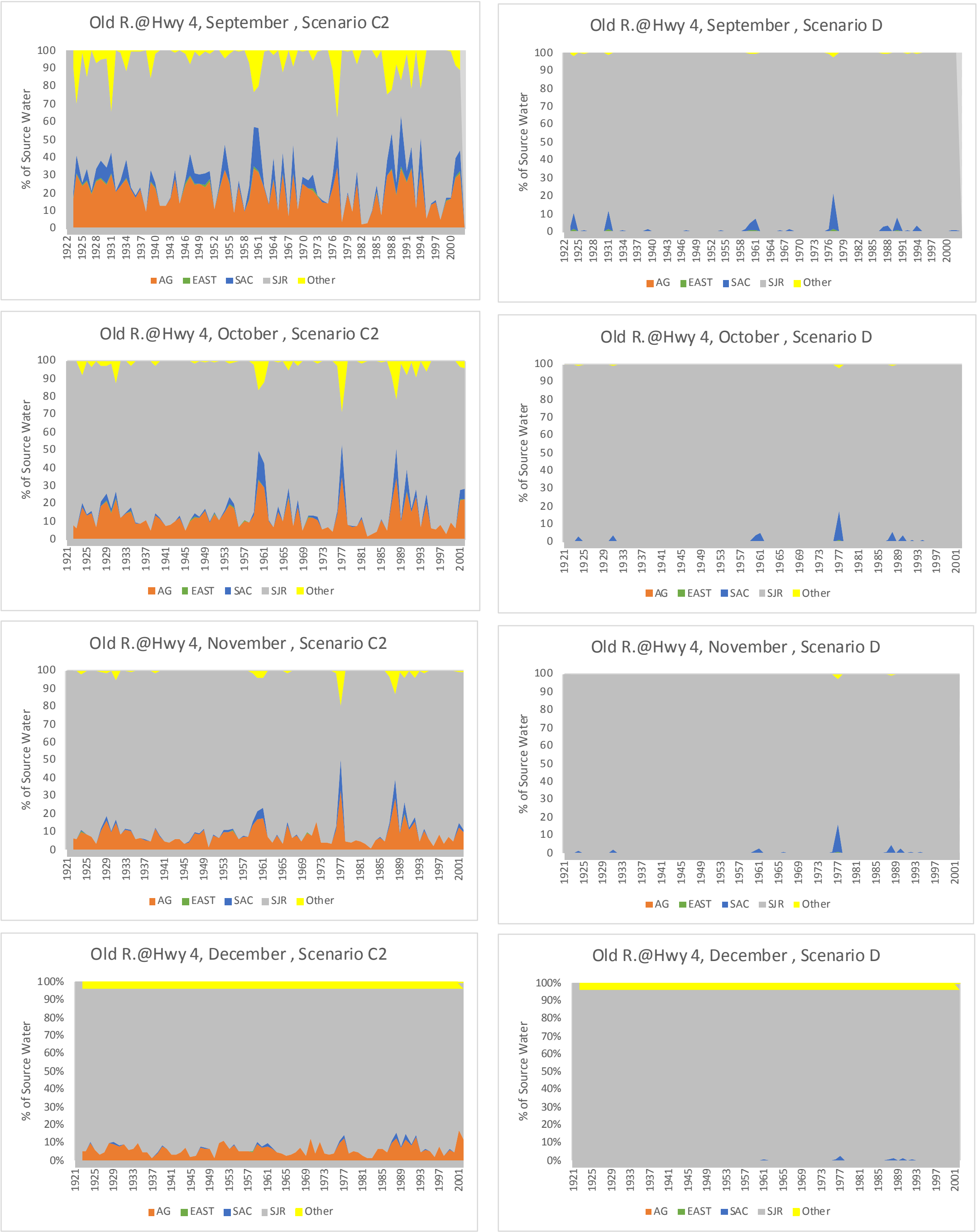


Figure 57 Rold034: Old River @ Hwy 4

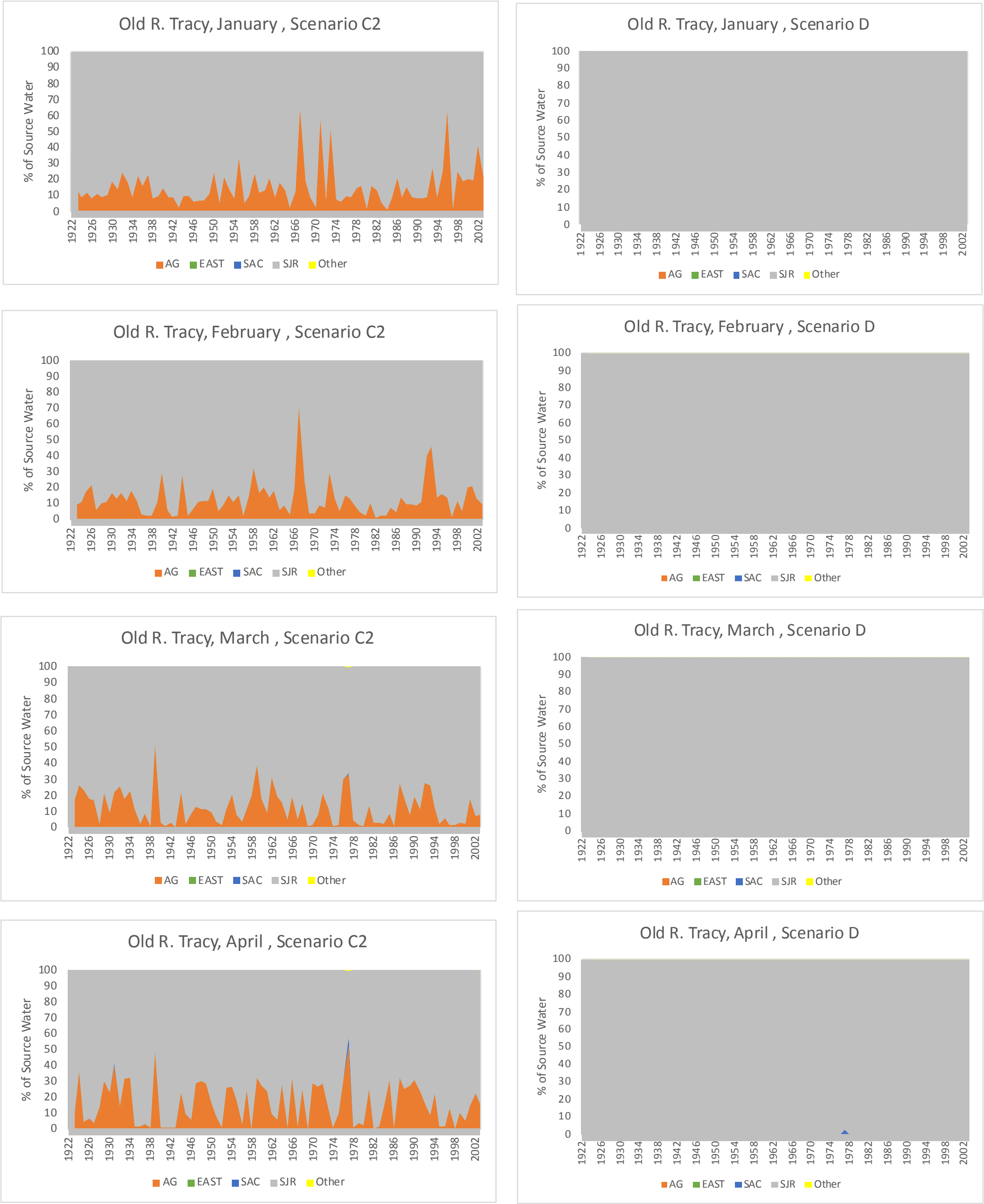


Figure 58 *ROld059: Old River @ Tracy*

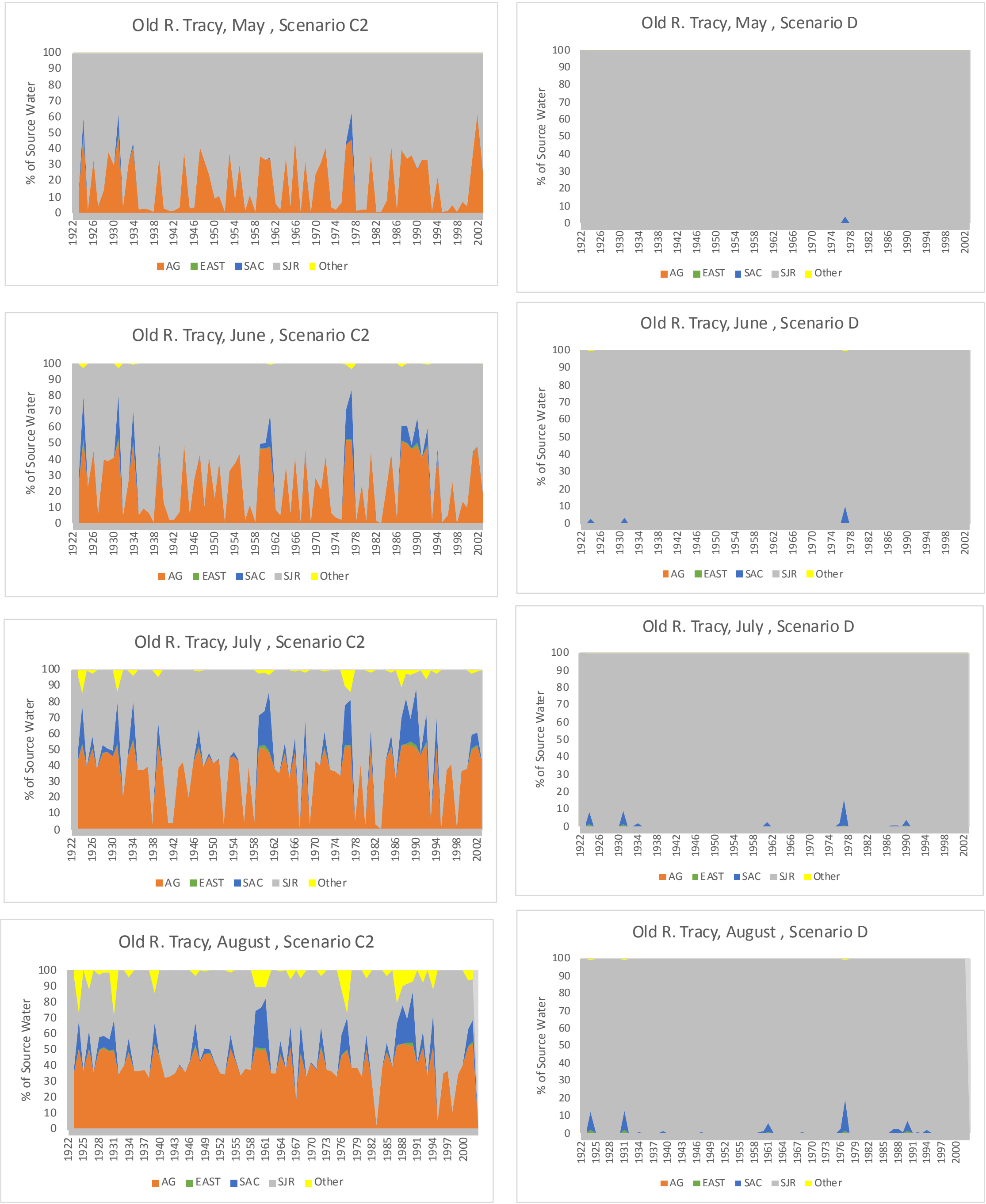


Figure 59 *Rold059: Old River @ Tracy*

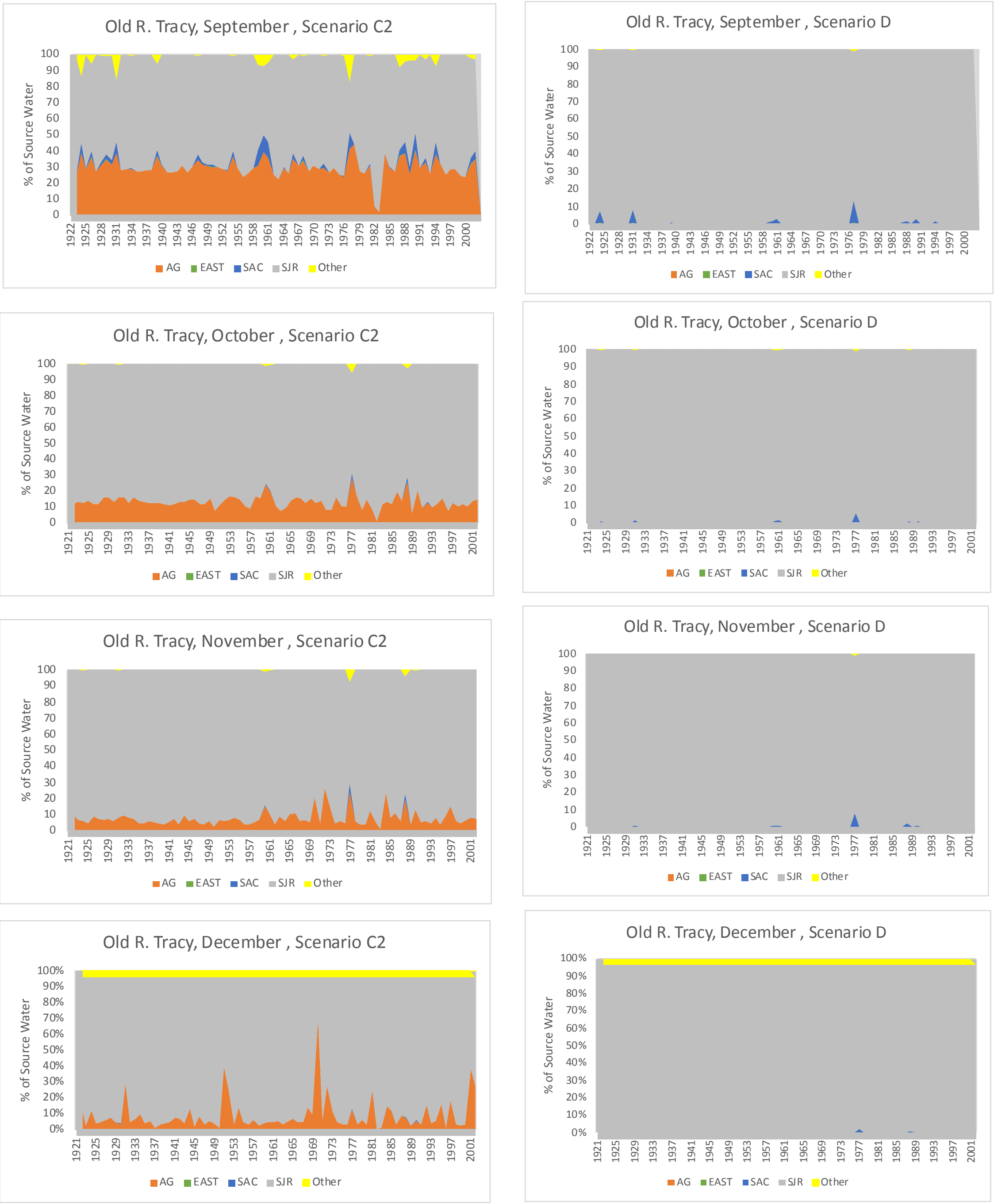
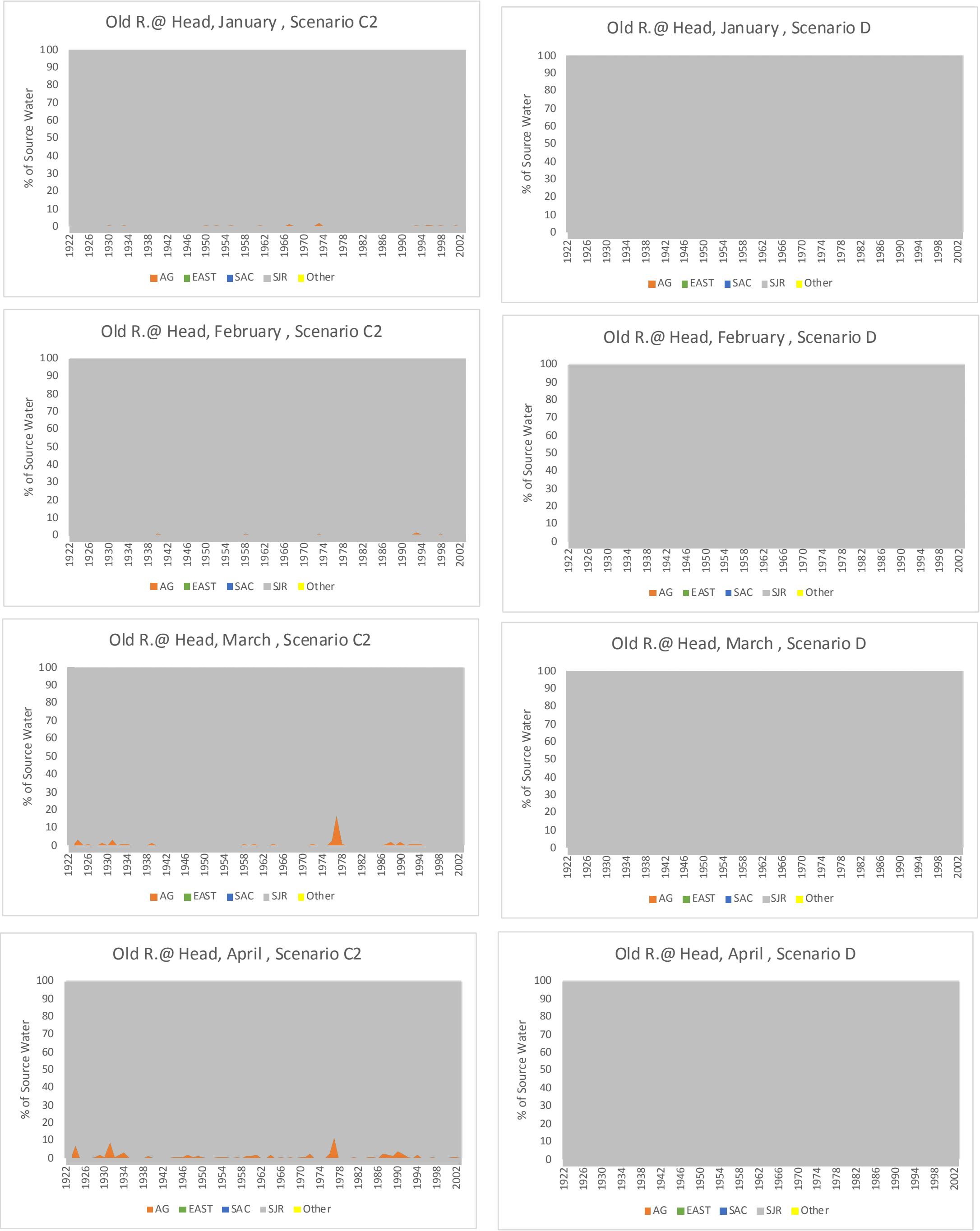


Figure 60 Rold059: Old River @ Tracy



Old R.@ Head, January , Scenario C2

Old R.@ Head, January , Scenario D

Old R.@ Head, February , Scenario C2

Old R.@ Head, February , Scenario D

Old R.@ Head, March , Scenario C2

Old R.@ Head, March , Scenario D

Old R.@ Head, April , Scenario C2

Old R.@ Head, April , Scenario D

Figure 61 Rold074: Old River @ Head

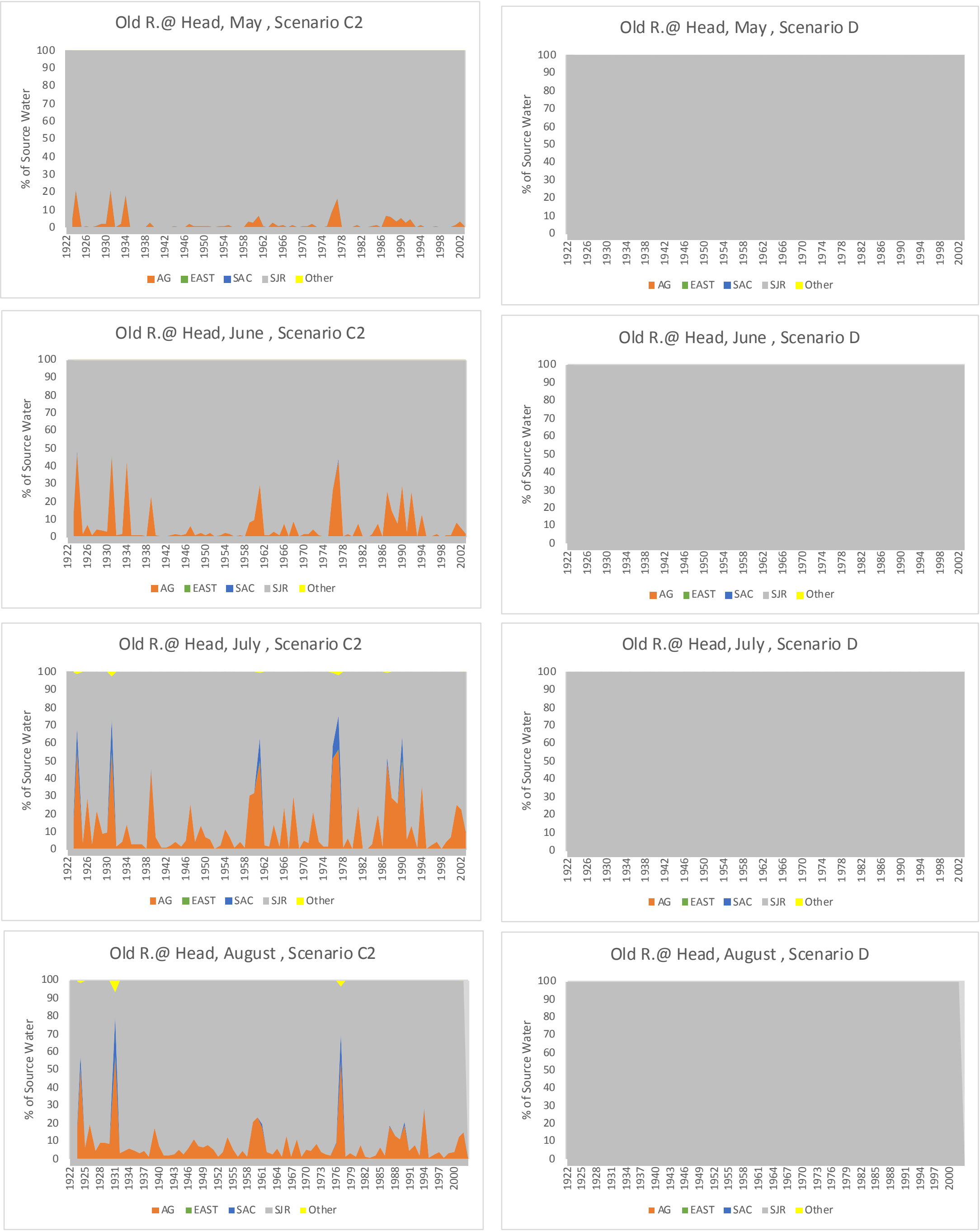


Figure 62 Rold074: Old River @ Head

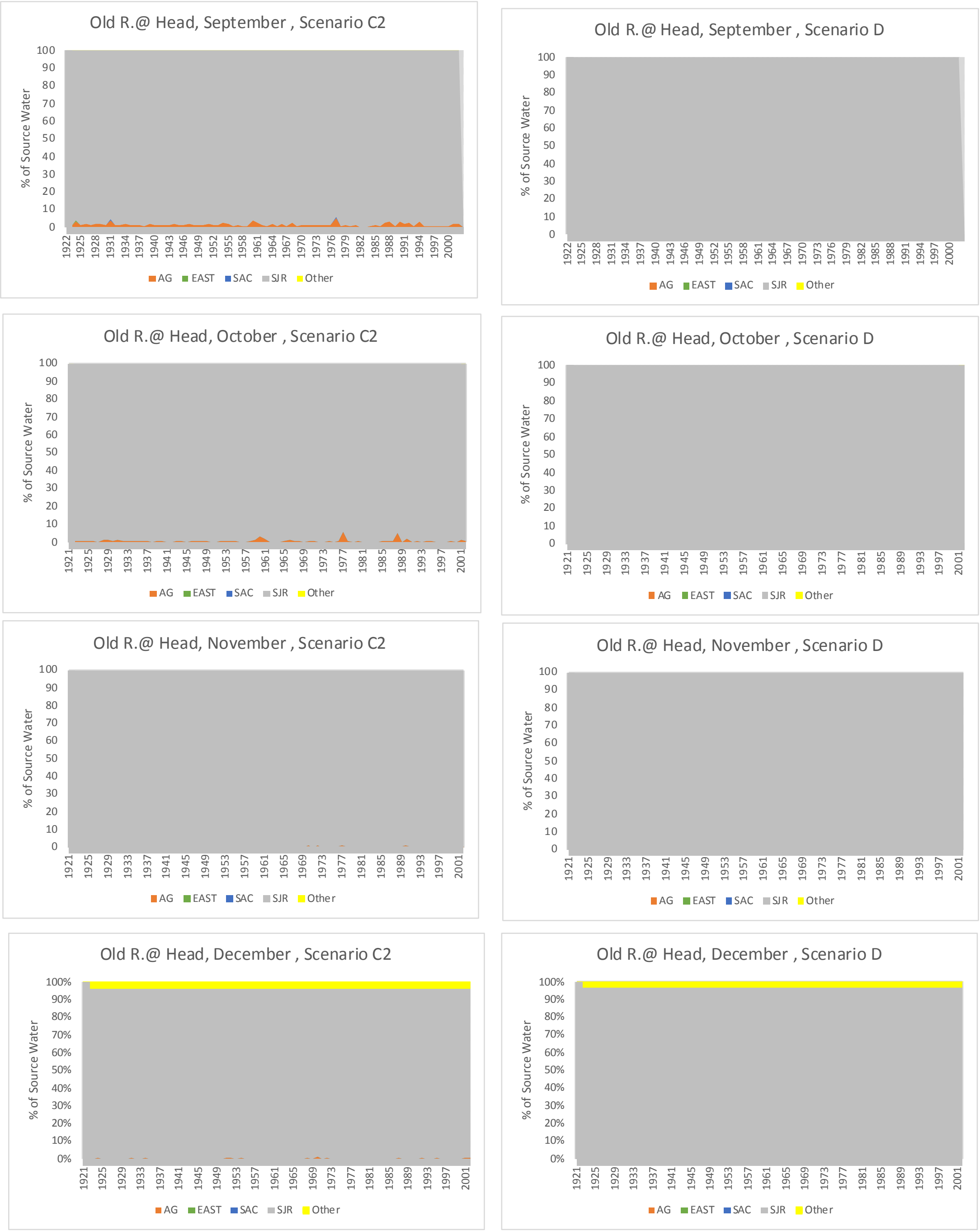


Figure 63 *Rold074: Old River @ Head*

APPENDIX B SCENARIO A DSG FITTING RESULTS

This appendix contains the parameter estimates and diagnostic plots from fitting the DSG model to DSM2 simulations of South Delta electrical conductivity data for Scenario A. See the results for Scenario C2 presented in Section 3 of the South Delta Diversion Curtailment Analysis document for more details.

Note that although the flows displayed in Figure 64 and Figure 65 are based on the DSM2 flow output at Martinez (MTZ), the DSG estimates are estimated using a G flow derived from the Net Delta Outflow Index, NDOI.

Table 3

Diagnostics of DSG predictions of DSM2-simulated EC for Scenario A in terms of a linear model $EC_{DSM} = a + b \cdot EC_{DSG}$ and best fit DSG parameters for two different estimation procedures: non-linear least squares (nls) and maximum a posteriori (map) fit of a Bayesian student's t model. Columns in gray are not estimated in model training.

			Model Diagnostics				**DSG Parameters (EC units: mS/cm, flow units: cfs)**							
Scenario	**Reach**	**Fit**	r^2	**Std. Error**	a	b	ϕ_1	ϕ_2	S_b	$\hat{S}$	S_c	γ	δ	$\beta \times 10^{-10}$
A	MID	map	0.91	0.39	0.02	1.03	758	-0.241	0.274	22.1	2.00	∞	1.00	1.5
A	MID	nls	0.91	0.39	0.00	1.00	693	-0.230	0.312	22.2	2.00	∞	1.00	1.5
A	OLD	map	0.90	0.40	0.03	1.02	749	-0.239	0.323	23.2	2.00	∞	1.00	1.5
A	OLD	nls	0.90	0.40	0.00	1.00	692	-0.230	0.365	23.1	2.00	∞	1.00	1.5
A	SJ	map	0.91	0.38	0.02	1.03	764	-0.242	0.267	21.9	2.00	∞	1.00	1.5
A	SJ	nls	0.91	0.38	0.00	1.00	695	-0.230	0.304	22.1	2.00	∞	1.00	1.5

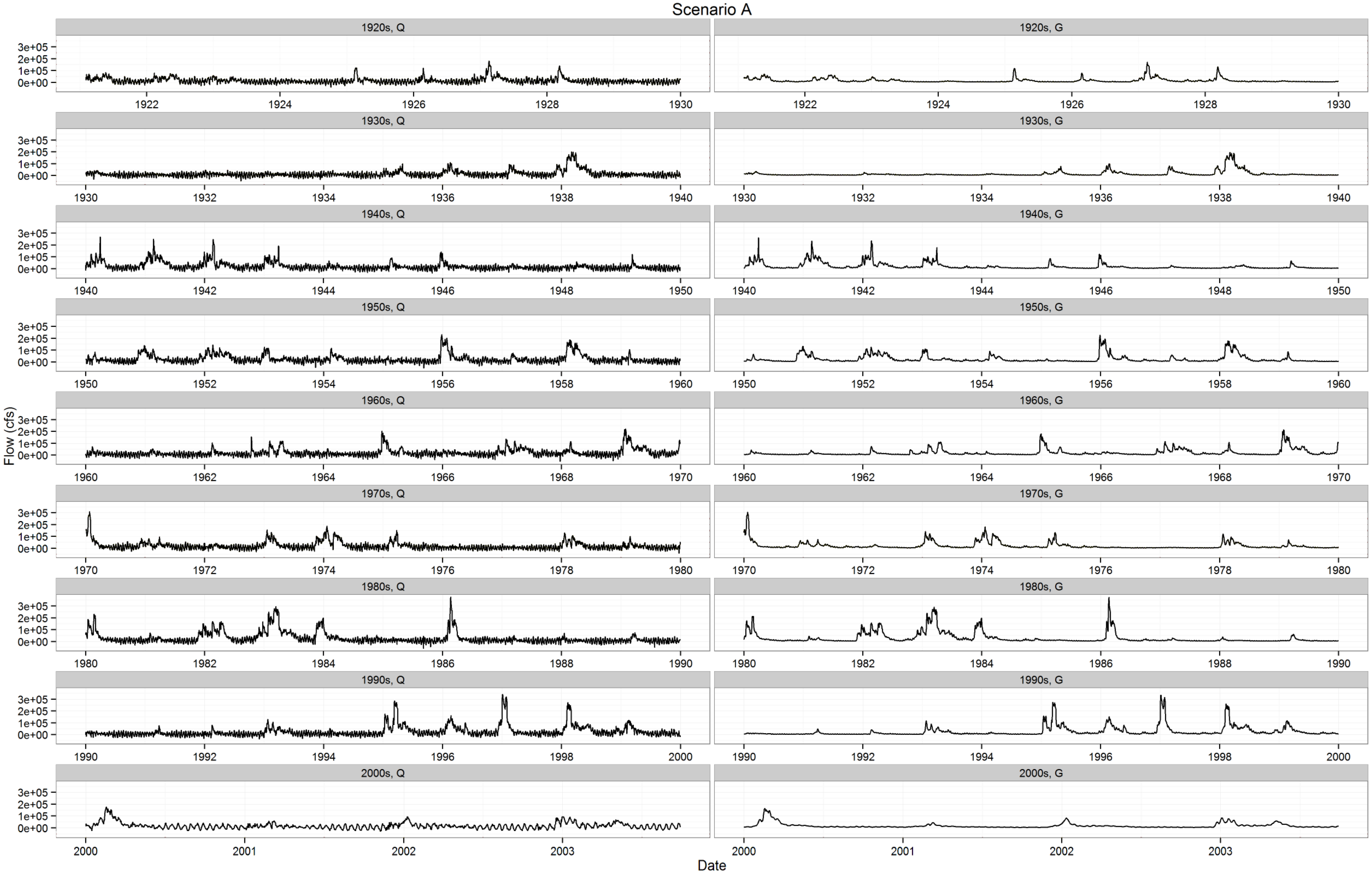


Figure 64 Time series plots of net Delta outflow, Q, approximated as modeled flow past Martinez, and corresponding antecedent flows, G, for Scenario A.

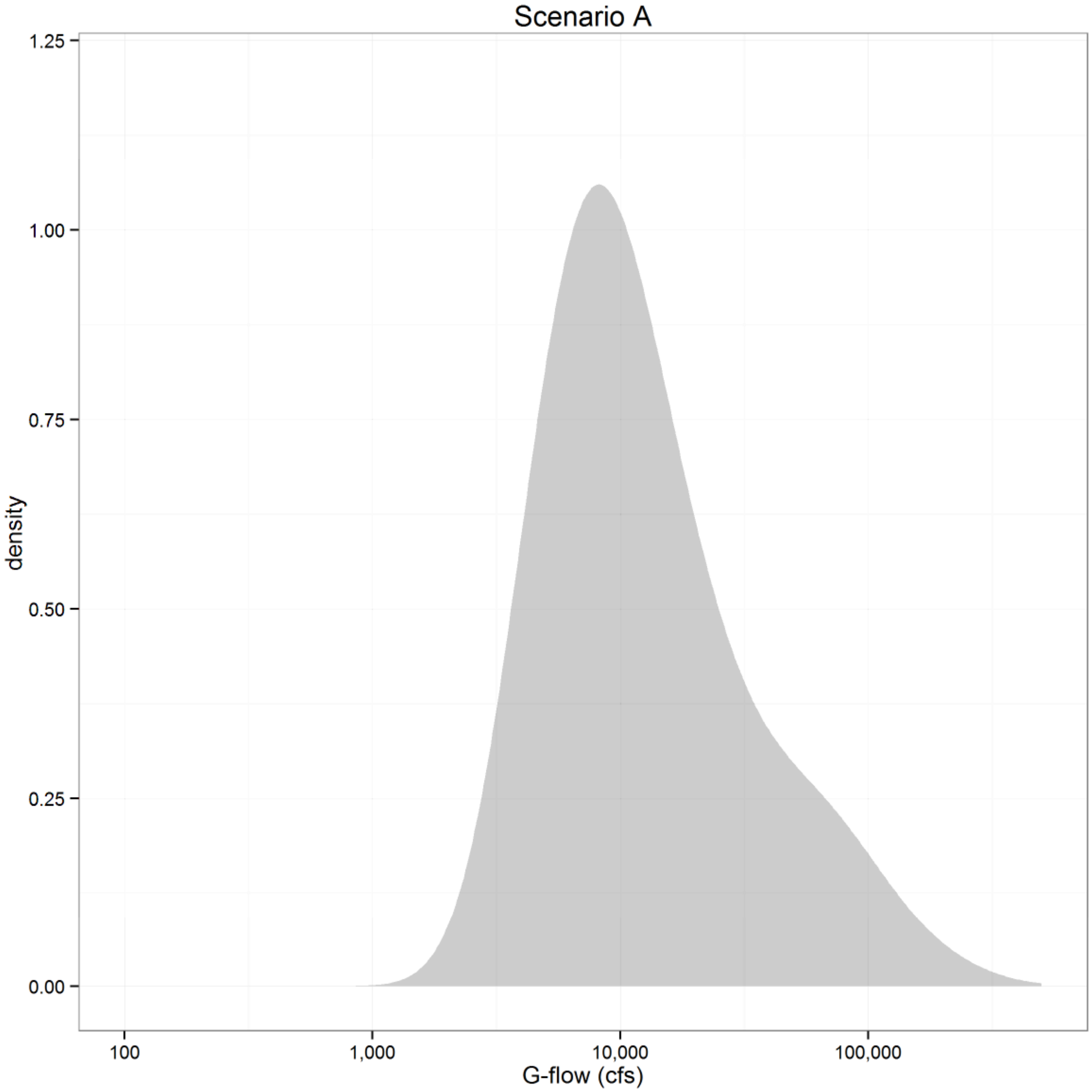


Figure 65 Scenario A smoothed frequency distribution of G-flow.

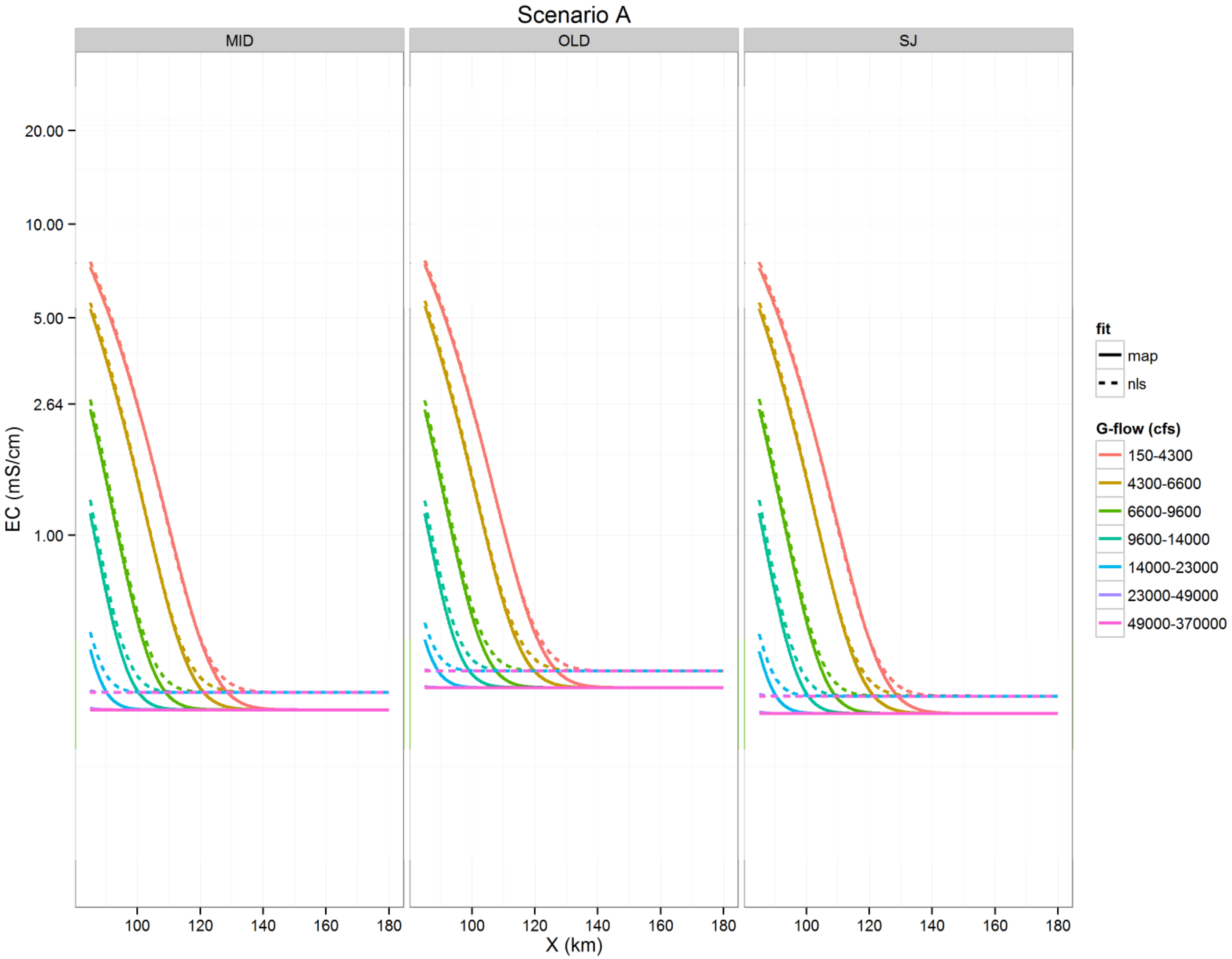


Figure 66 *Illustration of spatial variation in DSG predictions using the median G-flow in seven evenly spaced (in terms of G-flow percentiles) flow bins.*

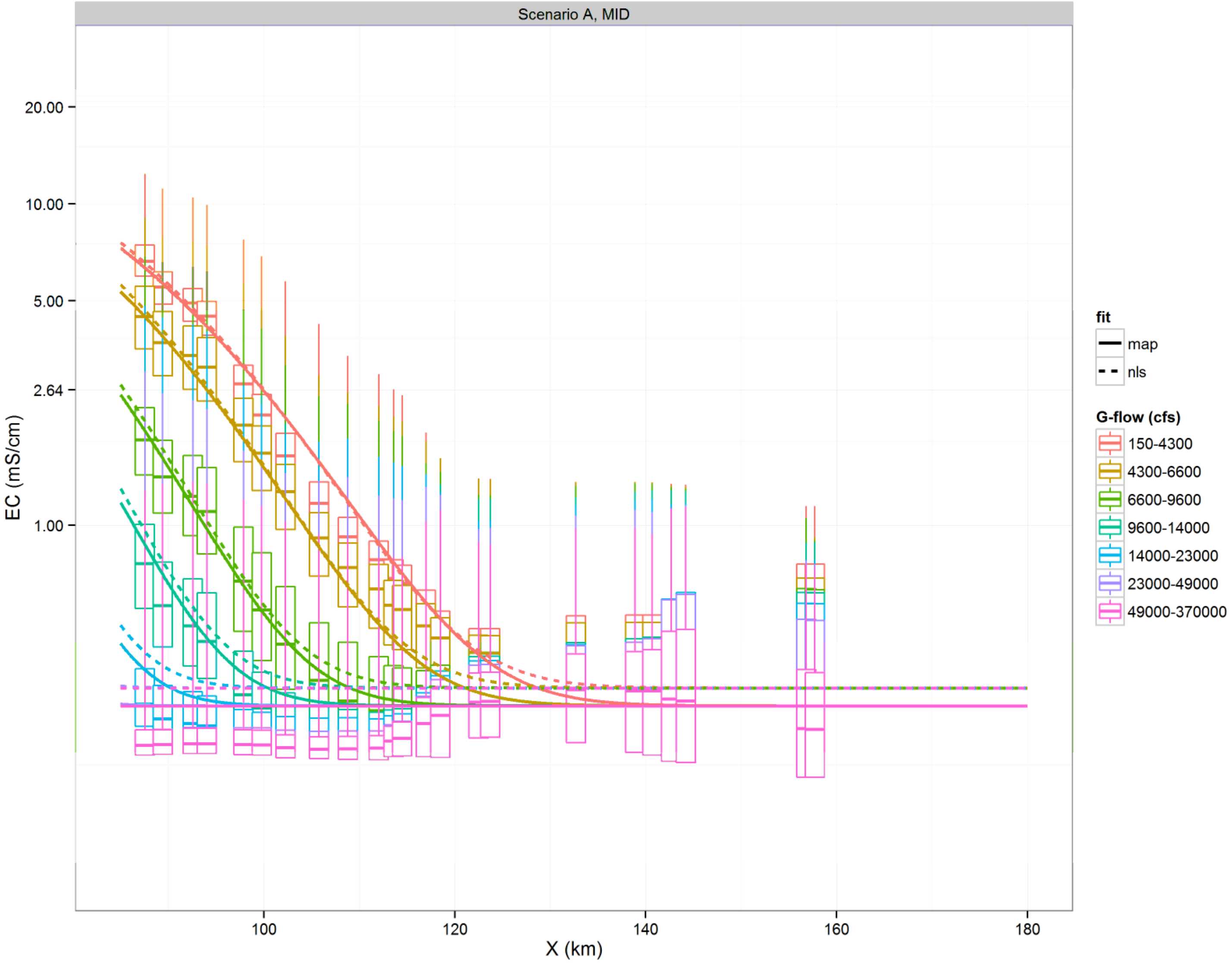


Figure 67 As in Figure 66, except with box plots showing the distribution of DSM2 data at each distance. Scenario A, Middle River.

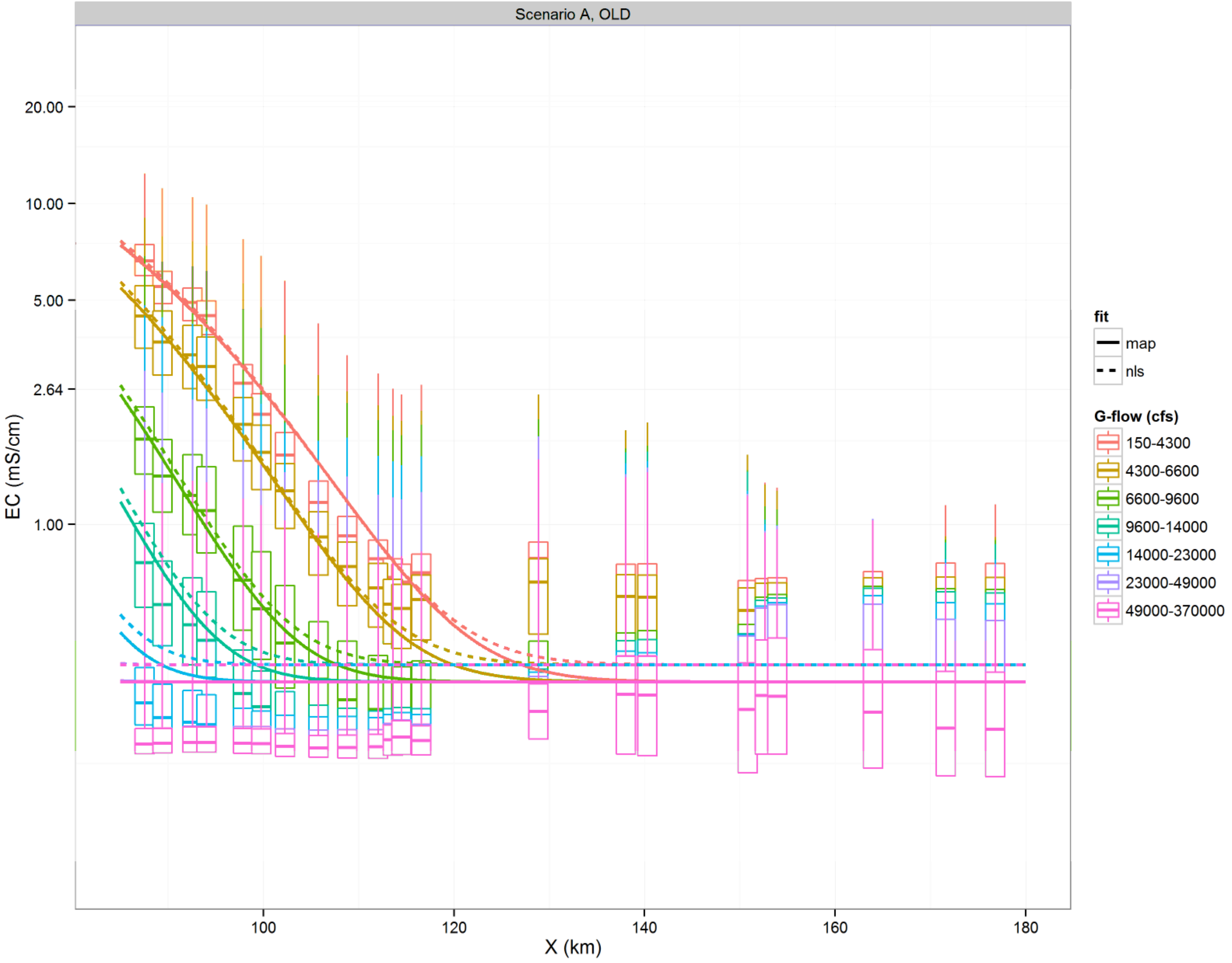


Figure 68 As in Figure 66, except with box plots showing the distribution of DSM2 data at each distance. Scenario A, Old River.

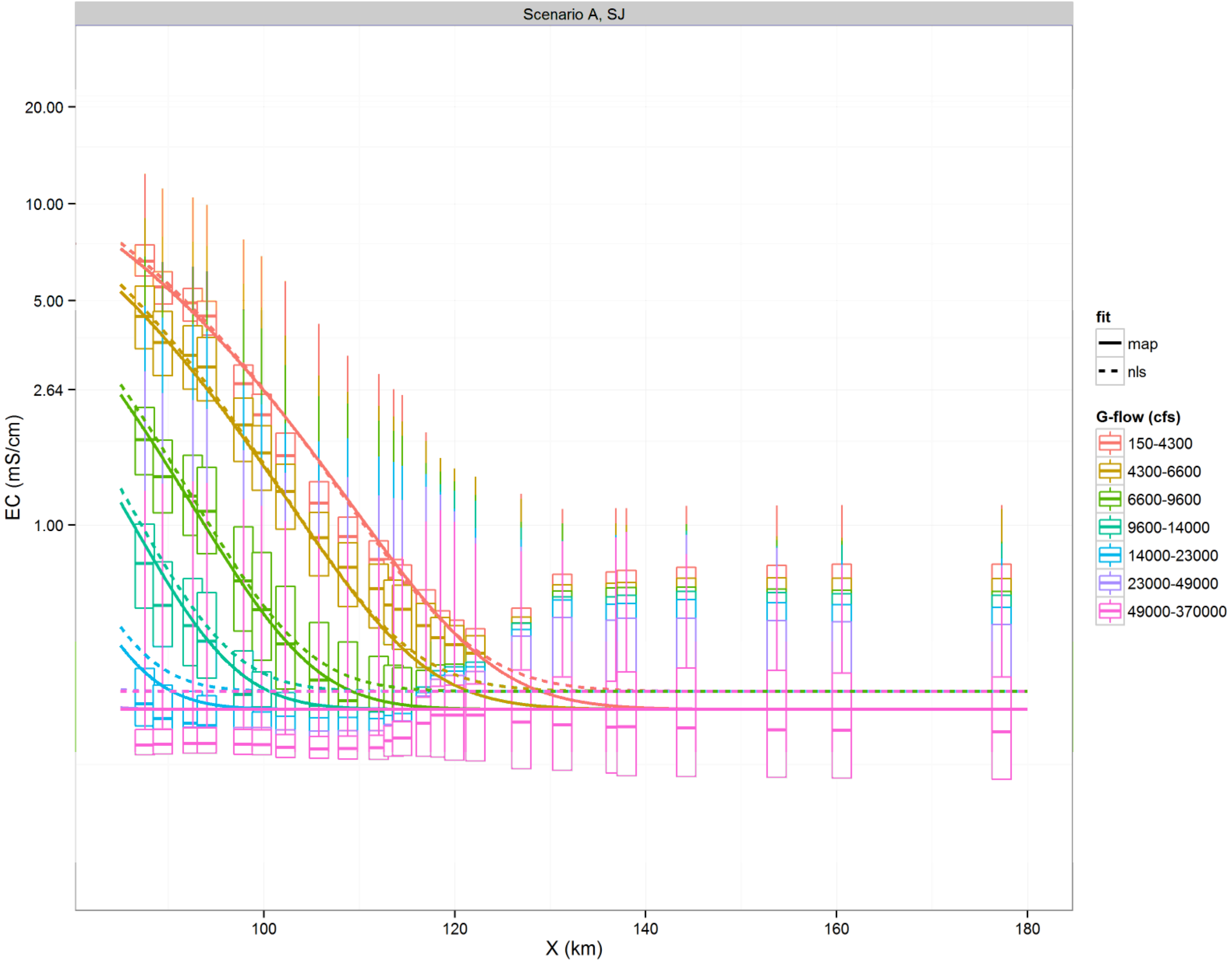


Figure 69 *As in Figure 66, except with box plots showing the distribution of DSM2 data at each distance. Scenario A, San Joaquin River.*

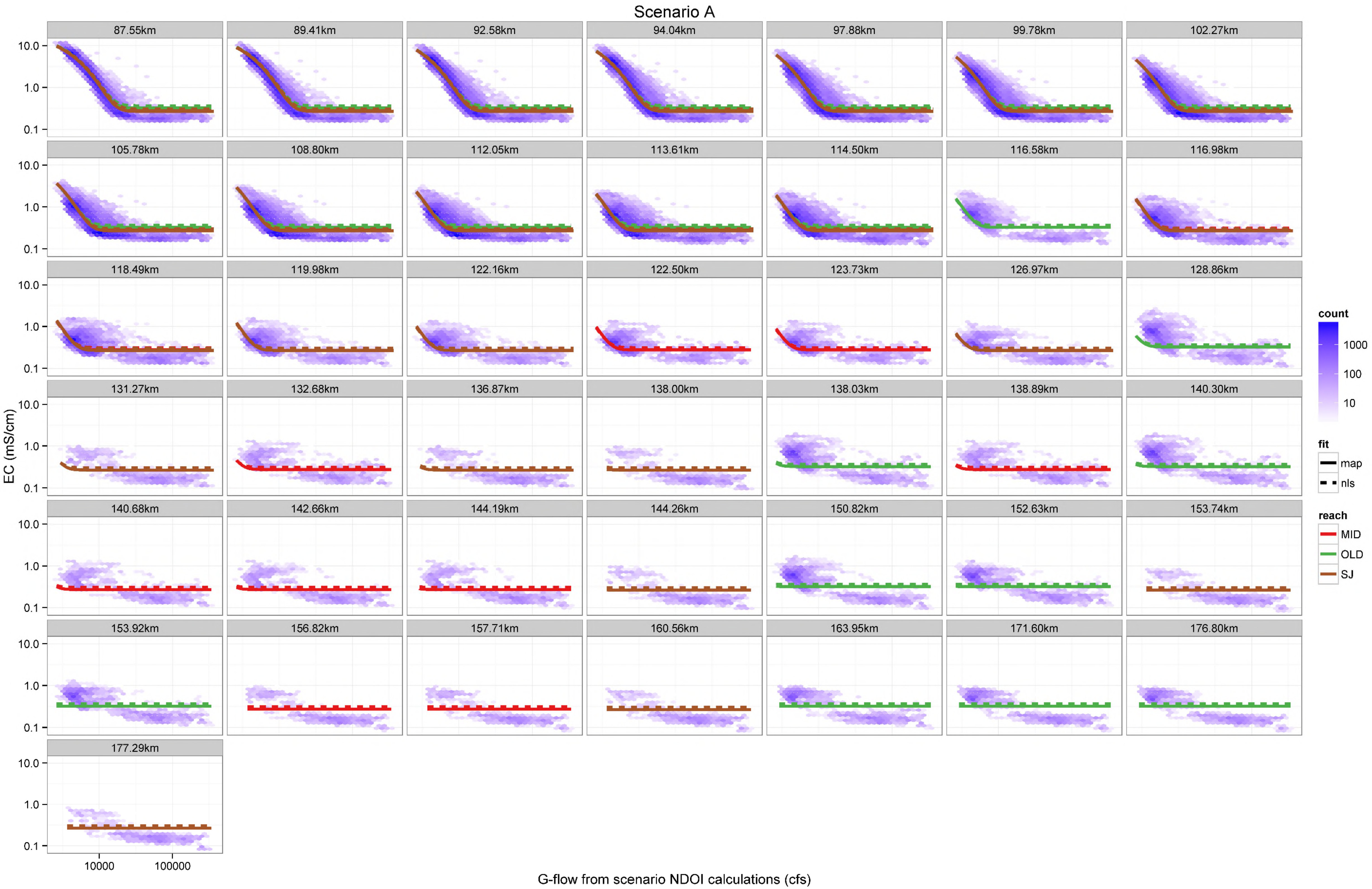


Figure 70 Flow response of DSM2 simulations and DSG predictions of EC at each DSM 2 location, Scenario A. Log scale on both axes.

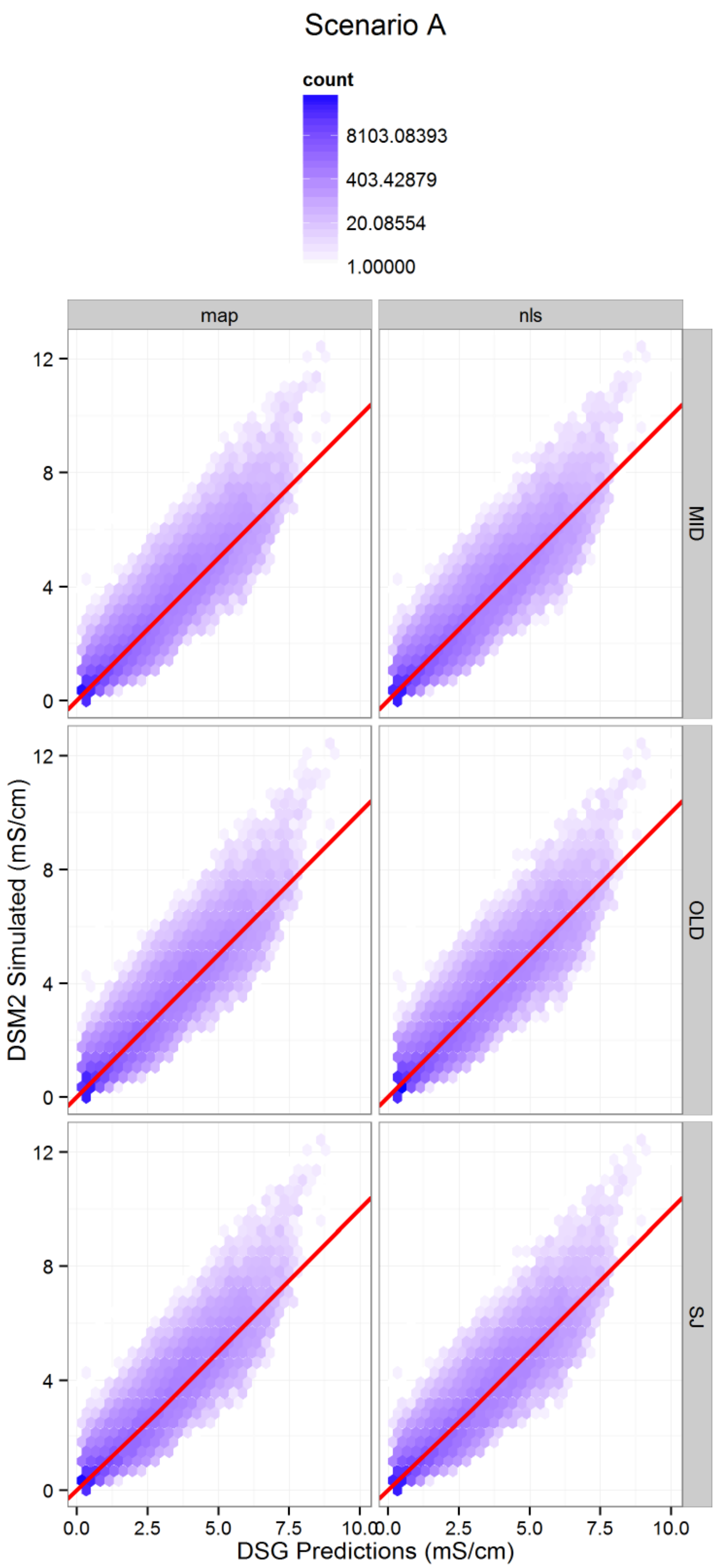


Figure 71 DSG predictions vs training data and 1:1 line (red).

Attachment 5

DRAFT TECHNICAL MEMORANDUM

2012 – 2015 Delta Salinity Conditions under a Without Project Scenario

PREPARED FOR:	Terry Erlewine/SWC
PREPARED BY:	Tyler Hatch/CH2M HILL Chandra Chilmakuri/CH2M HILL
DATE:	June 5, 2015

Study Objective

The purpose of this study is to analyze salinity conditions in the south Delta channels under a Without Project scenario using the January 1, 2012 to August 31, 2015 Central Valley rim inflows. 2012 - 2015 historic and projected Sacramento River and San Joaquin River inflows to the Delta were modified to remove the impairments related to the upstream CVP – SWP reservoirs under the Without Project Scenario in addition to zeroing out the Delta exports at the Banks and Jones Pumping Plants and closing the Delta Cross Channel. The 2012 – 2015 study is an extension of a previous study of Without Project conditions for the year 2014. The multi-year timeframe allows understanding Delta salinity conditions under a sequence of differing hydrologic conditions.

Approach

A DSM2 model capable of simulating 2012-2015 historical Delta hydrodynamics and salinity conditions obtained from the DWR was used for representing the With Project scenario in this task. DWR used 2012 – 2015 Delta inflows, exports and salinity as the boundary conditions for the DSM2 model.

For the 2012-2015 Without Project DSM2 model, adjusted daily Delta inflow data at Vernalis and Freeport provided by the SWC were used as boundary conditions. As shown in Figures 1 and 2, Sacramento and San Joaquin Without Project inflows to the Delta are significantly lower (in some cases negative) in the summer and fall months compared to the historical conditions primarily due to the lack of contributions from project reservoir storage. The Without Project Scenario also assumed zero Delta exports from Banks and Jones Pumping Plants. The Without Project DSM2 model also uses historical electrical conductivity estimates for salinity boundary conditions at Freeport consistent with the historical DSM2 model. However, for the San Joaquin River at Vernalis modified electrical conductivity estimates were used to account for the unimpaired conditions under the Without Project scenario. The modified Vernalis EC estimates for the Without Project scenario were computed based on a methodology provided by the SWC, which is outlined in the Appendix A of this memo. For the Without Project conditions, the Delta Cross Channel gates were assumed to be closed for the entire length of the simulation.

Clifton Court Forebay (CCF) gate operations under the historical and Without Project DSM2 simulations were modified to represent Priority 3 gate operations. Under the Without Project simulation, instead of relocating BBID's existing DICU diversion from inside the CCF and closing the CCF gates, the With Project CCF gate operations were assumed to allow for the BBID diversion to continue. Even though the CCF gates are operational under the Without Project scenario, resulting Clifton Court inflow (Figure 3) confirms that inflow to CCF occurs only during the months with BBID diversion.

Sacramento River at Freeport timeseries input into the Without Project DSM2 model used only the positive flows provided. All negative flows were set to zero. Figure 1 below shows a comparison of the historical record, the Without Project timeseries with negative values from SWC, and the timeseries input into DSM2. In the summer months, the demands upstream of the Delta exceed the supply when there is no storage available to supplement the river flows into the Delta.

For the San Joaquin River at Vernalis, the Without Project DSM2 simulation used a 20 cfs base flow, when the Without Project flows from SWC are negative in order to achieve model stability in the channels near the San Joaquin River boundary in the DSM2 model. This base flow was used to keep water in the few channels downstream of Vernalis and was diverted upstream of the Old River (model node 4). Figure 2 shows a comparison between the historical Vernalis flows, the Without Project flows from SWC, and the Without Project flows used in the DSM2 simulation. In addition, the diversion component of the Delta Island Consumptive Use (DICU) in the channels near the San Joaquin River boundary (at node 1 and 3) were set to zero when the base flow was the only flow assumed in the model at Vernalis. Without curtailing the DICU diversions at model nodes 1 and 3, the base flow would have to be large enough to meet the DICU demand and keep water in the channel.

Based on the modified electrical conductivity at Vernalis under the Without Project conditions, zero or negative flows have zero electrical conductivity. This assumption of zero EC was continued even though 20 cfs base flow was assumed under the Without Project scenario. However, the artificial base flow of 20 cfs with zero EC could therefore dilute salinity in the San Joaquin River near the Vernalis boundary that would otherwise exist in higher concentrations. A sensitivity analysis using the same model and assuming 2014 historical salinity for the 20 cfs base flows shows that the resulting salinity in the San Joaquin River near the Vernalis boundary is somewhat sensitive, but the differences are minimal beyond model node 4. In addition, while the DICU diversion values are set to zero at nodes 1 and 3, the DICU drain flow is continued in the model, which continues to add salt to the Delta channels.

For conditions projected from May 2, 2015 to August 31, 2015, stage and electrical conductivity at the downstream boundary was assumed at 2014 values for both the With Project and Without Project scenarios. For the With Project conditions, 2014 conditions were assumed for May 2, 2015 to August 31, 2015 for all inflows and outflows with the exception of inflows at Freeport and Vernalis and outflows for SWP and DMC. Projected 2015 with project flows at Vernalis were calculated as the sum of New Melones monthly outflows and San Joaquin River above the Stanislaus River flows after removing any contractor deliveries from the forecasted operations provided by the U.S. Bureau of Reclamation to the SWRCB in support of the 2015 TUC petition (http://www.waterboards.ca.gov/waterrights/water_issues/programs/drought/docs/tucp/2015/inputsheet_april90_upstream_ops.pdf). Projected 2015 With Project flows at Freeport were estimated as the balance of Delta monthly inflows and outflows, and assuming SWP and CVP Delta exports to be zero for May through August 2015. The Without Project simulation used the same boundary inflows and diversions as the With Project simulation for May 2, 2015 to August 31, 2015 period with the exception of Sacramento River at Freeport and San Joaquin River at Vernalis inflows, which were assumed to be zero. Figures 1 and 2 show the assumed inflow boundary conditions for 2015 projected conditions.

Results

Due to a lack of inflow at both Freeport and Vernalis during the summer and fall months under the Without Project scenario, salinity is much higher in the Delta compared to the historical conditions. During these months there is no fresh water to dilute the higher salinity intrusion, and as a result, the tide brings saltier water further into the Delta. In figures 5 to 52, the saltwater-freshwater interface has moved much further inland by the end of June in the Without Project Scenario than the With Project conditions. The Sacramento River inflows tend to be much higher than the San Joaquin River inflows and cause the salt to be in higher concentrations in the south Delta. However, low flows in the Sacramento River allow the salt concentrations to be relatively high in the north Delta as well. By September the flows in the Sacramento River are high enough to push the saltwater interface further to the south. The area around Frank Tract tends to hold higher salinity water late into the year even after the Sacramento and San Joaquin Delta inflows have flushed much of the saltwater back out of the Delta. The contribution of New Melones Reservoir to flows at Vernalis appears to be a major component of the historical flows during the summer and fall months. Contour plots of weekly EC conditions for 2012 - 2015 are provided as electronic attachments to this memorandum.

Martinez EC Sensitivity Simulations

To consider the potential effect of modified NDOI on the Martinez EC boundary condition, a sensitivity analysis was performed of the modeled salinity under the With Project and Without Project cases by using the Martinez salinity boundary condition estimated using the DWR's G-Model, instead of the historical Martinez EC values. Figure 4 compares the daily-average Martinez EC values for the historical conditions, G-model estimates using With Project NDOI, and G-model estimates using Without Project NDOI. The G-Model salinity values are higher on average than the historical salinity used. DSM2 model for both With Project and Without Project cases were simulated with G-model based EC values specified at Martinez. DSM2 results showed that the higher salinity conditions extended further into the Delta under both the With Project and Without Project cases. Since the Martinez tide and the hydrology used remained unchanged under the sensitivity runs, the resulting hydrodynamics remained consistent with the original simulations. Therefore, using the G-model based EC values resulted in similar durations of salinity as compared to the simulations using historical Martinez EC.

Summary

The results in this memorandum show that without the CVP-SWP project reservoir storage, salinity would be much higher in the Delta during dry years than under the historical (With Project) conditions. There appears to be some pockets of higher salinity that persist late into the fall months in the central/south Delta channels over the multiple dry years simulated. However, due to the higher storm flows into the delta in the Without Project scenario, the driest years still have most of the salinity flushed east of Antioch in the spring months. The high salinity in the summer and fall months would further limit the beneficial use of water from the Delta during years like 2012 through 2015 under the Without Project scenario.

Limitations

Simulation of Delta salinity under With Project conditions and Without Project conditions using DSM2 are subject to limitations of the model and the approach used. DSM2 limitations and uncertainties are well documented in the DWR Annual Reports (http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/annualreports.cfm).

Salinity in San Joaquin River upstream of Head of Old River is likely not accurate due to artificial base flows assumed for model stability, and curtailing of the DICU diversions upstream of Head of Old River (at model nodes 1 and 3), under the Without Project scenario. Projections of Delta inflows and exports for May – Aug 2015 are also subject to change.

The salinity contour plots presented in this memorandum were created from point data in the model using kriging. As a result, the zones where the contours are calculated may be influenced by a neighboring channel without direct access to comingled salinity. An example of this is the Sacramento Deep Water Ship Channel and the Sacramento River on September 6, 2014.

FIGURE 1: SACRAMENTO RIVER AT FREEPORT DSM2 MODEL INFLOW FOR 2012 TO 2015

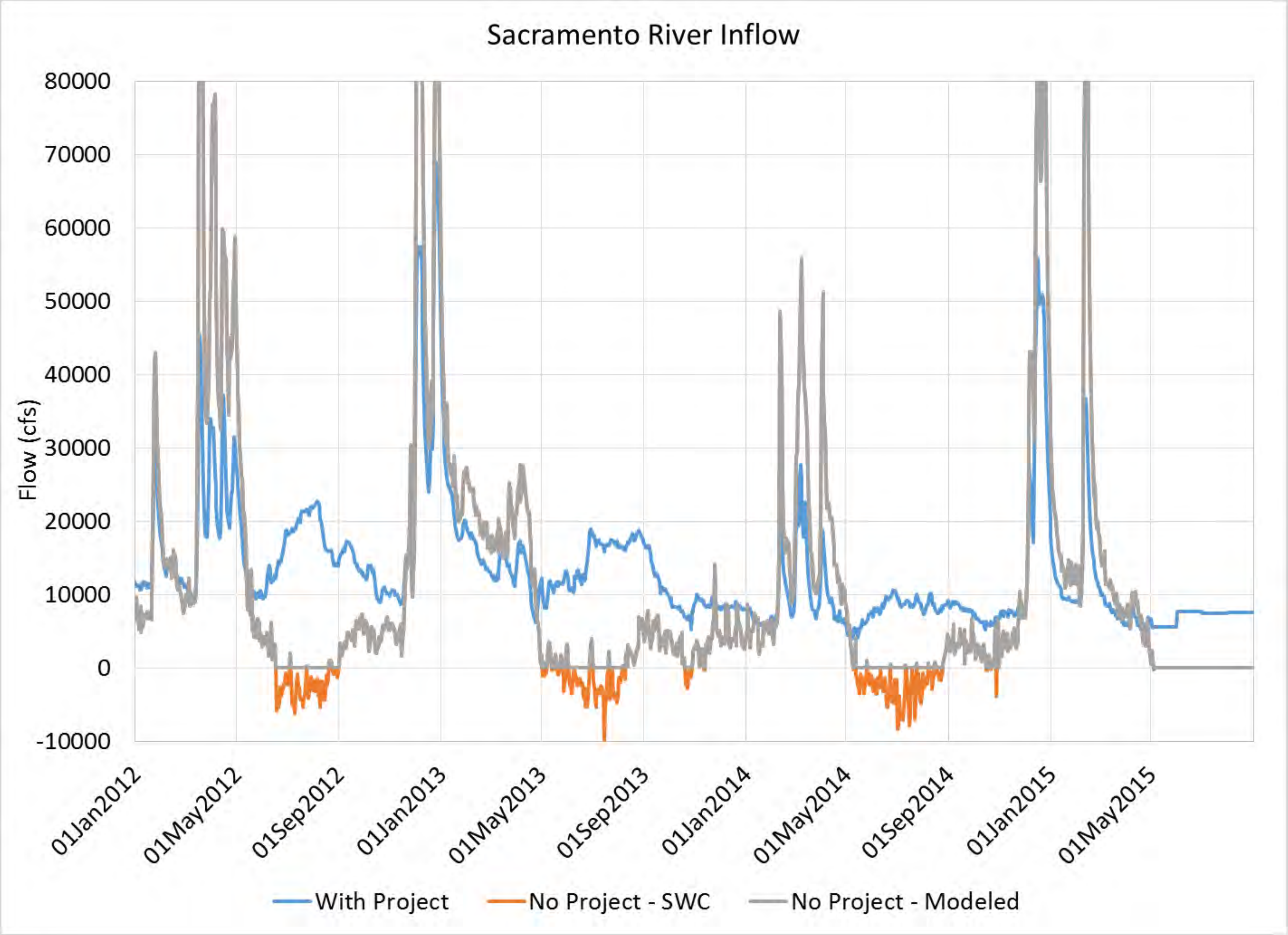


FIGURE 2: SAN JOAQUIN RIVER AT VERNALIS DSM2 MODEL INFLOW FOR 2012 TO 2015

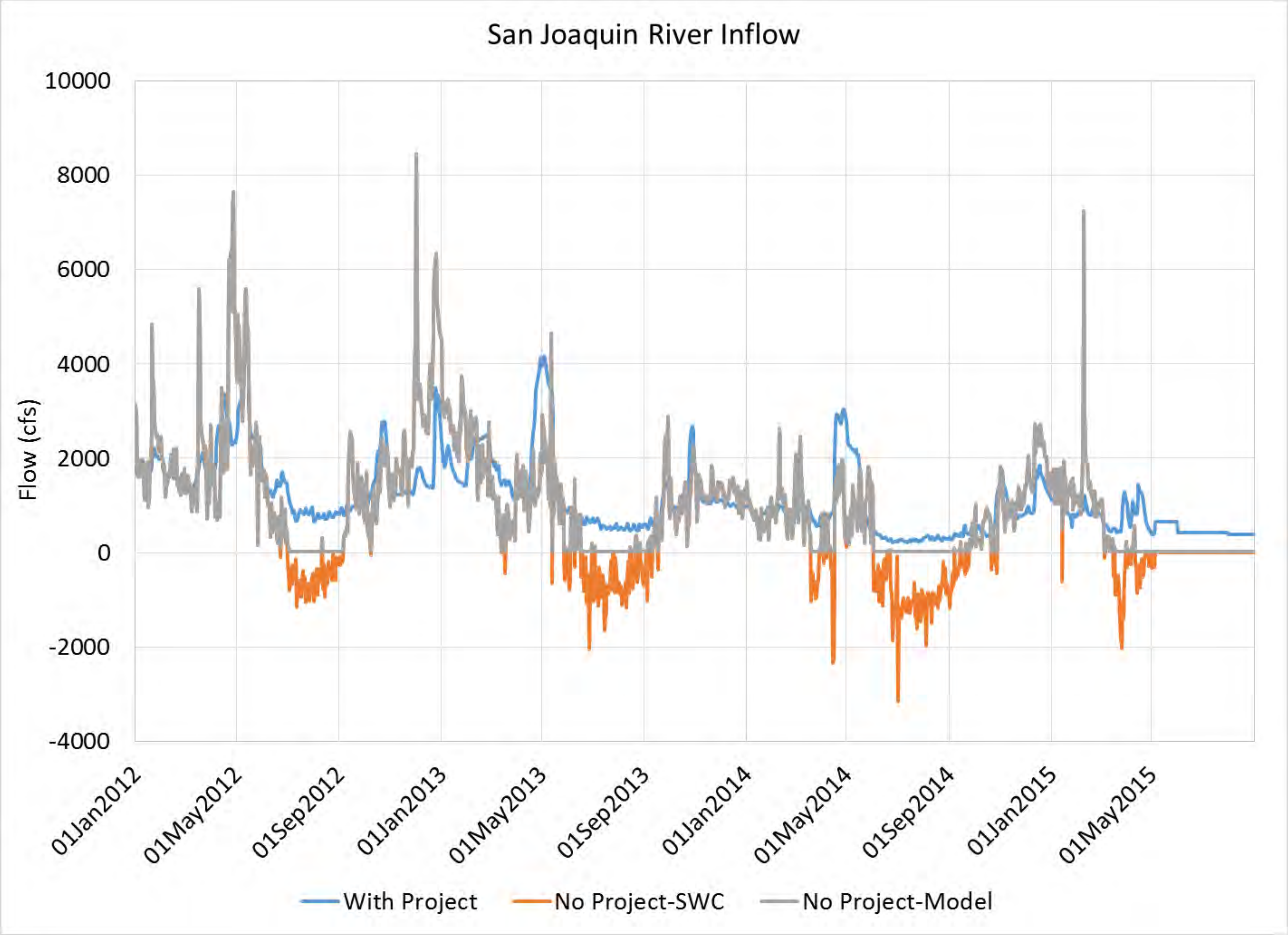


FIGURE 3: ASSUMED BBID DICU DIVERSION, AND DSM2 RESULT OF CLIFTON COURT FOREBAY INFLOW

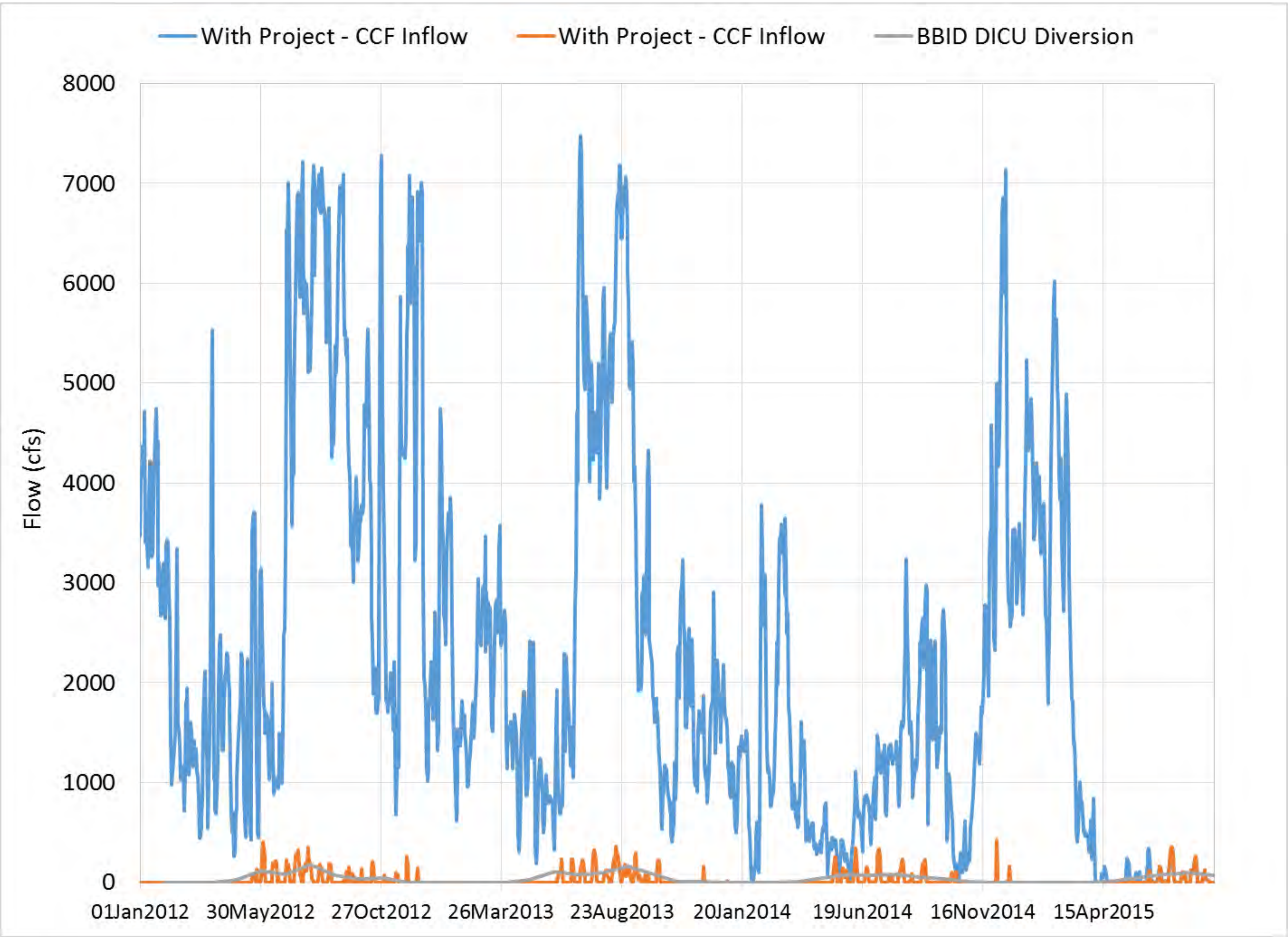
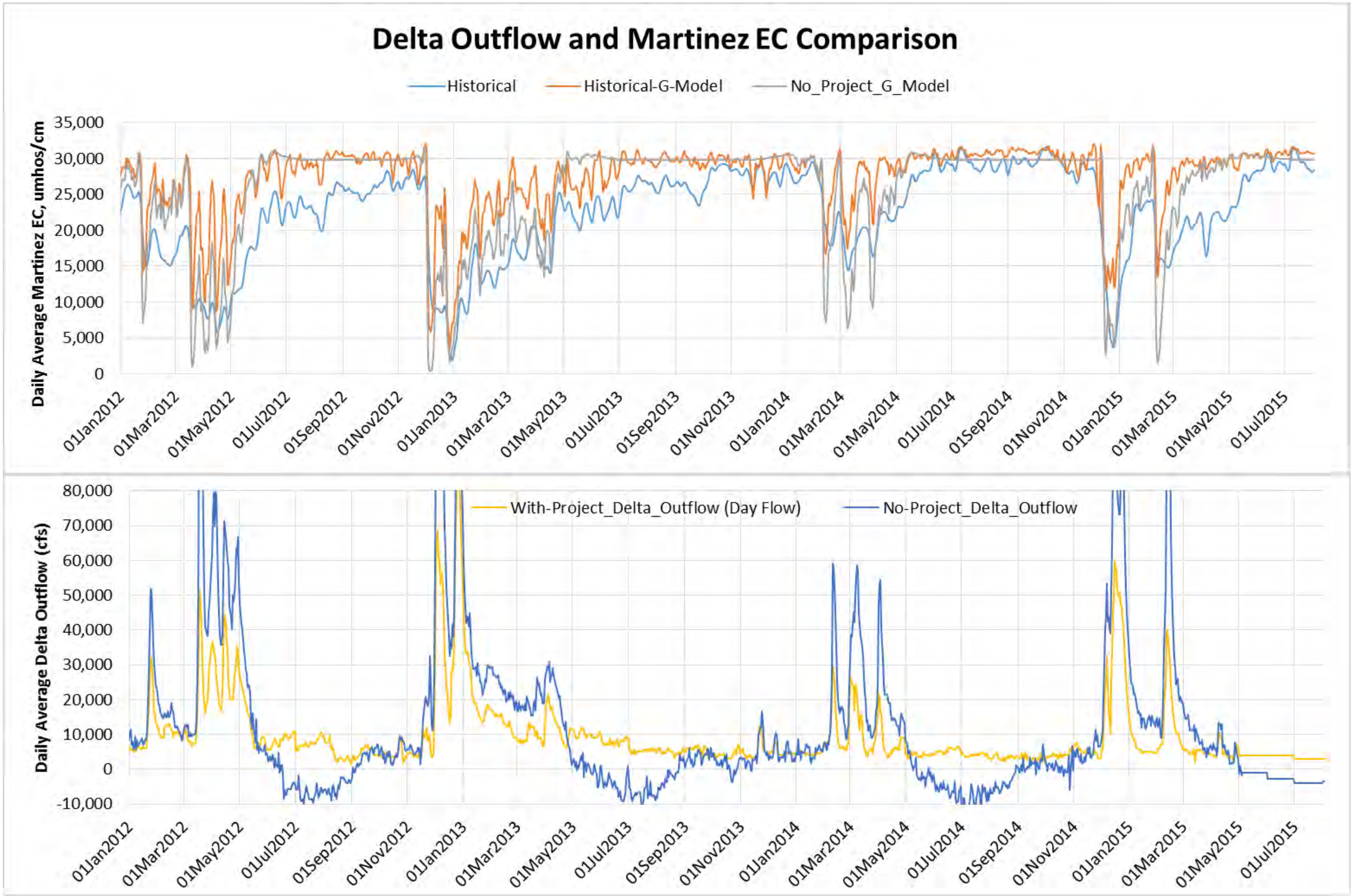
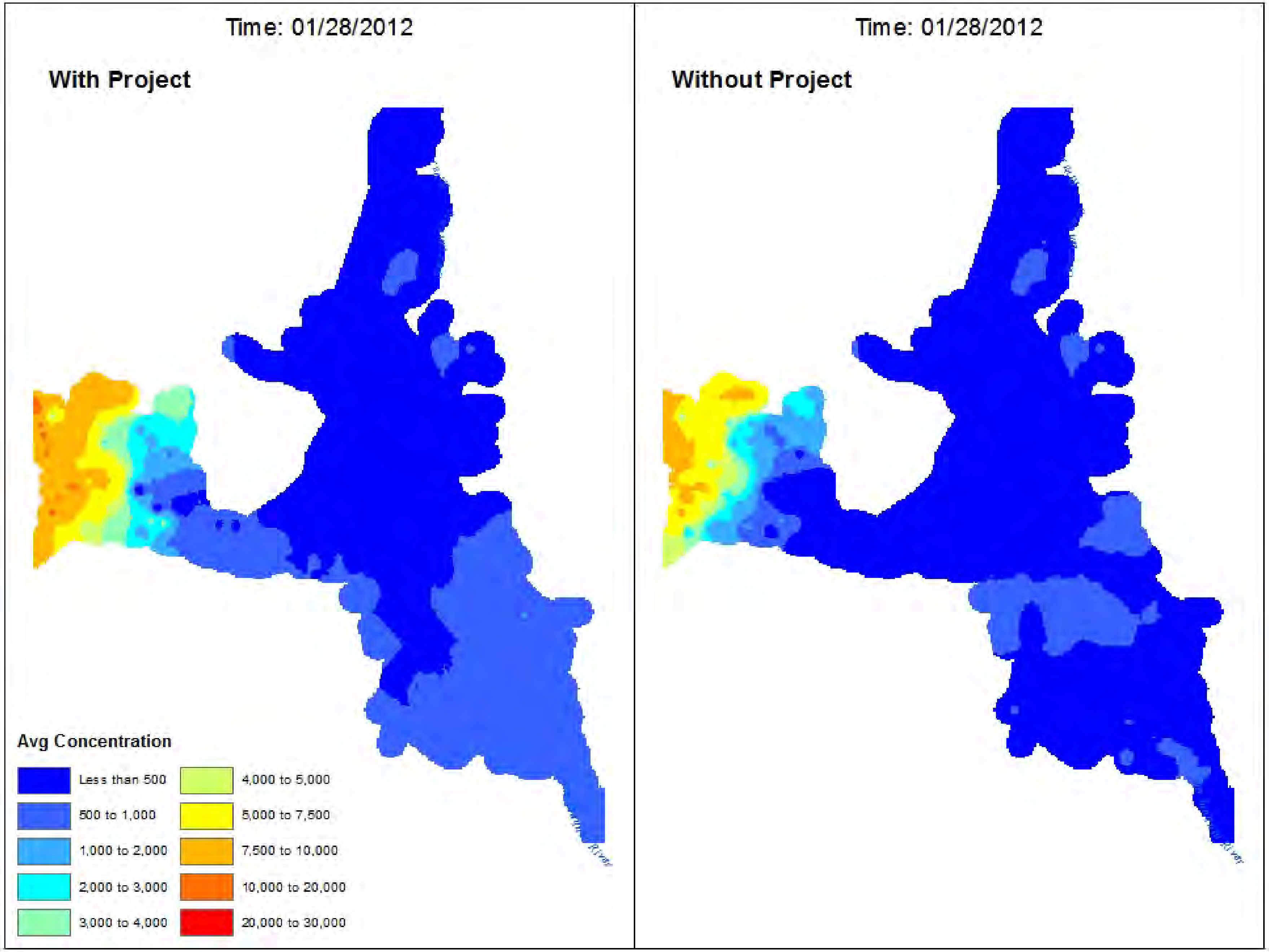


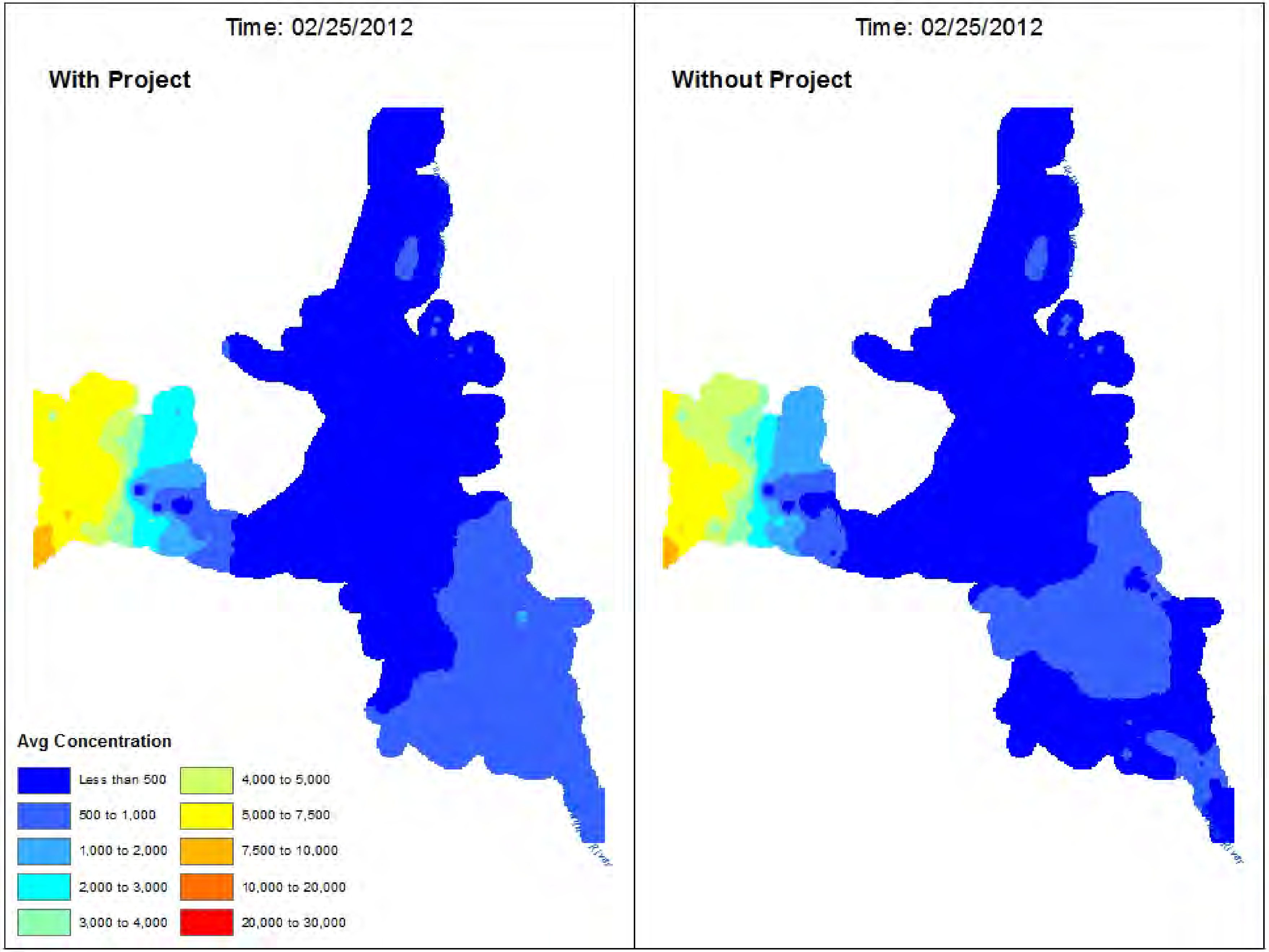
FIGURE 4: DAILY AVERAGED EC AT MARTINEZ FOR 2012 TO 2015

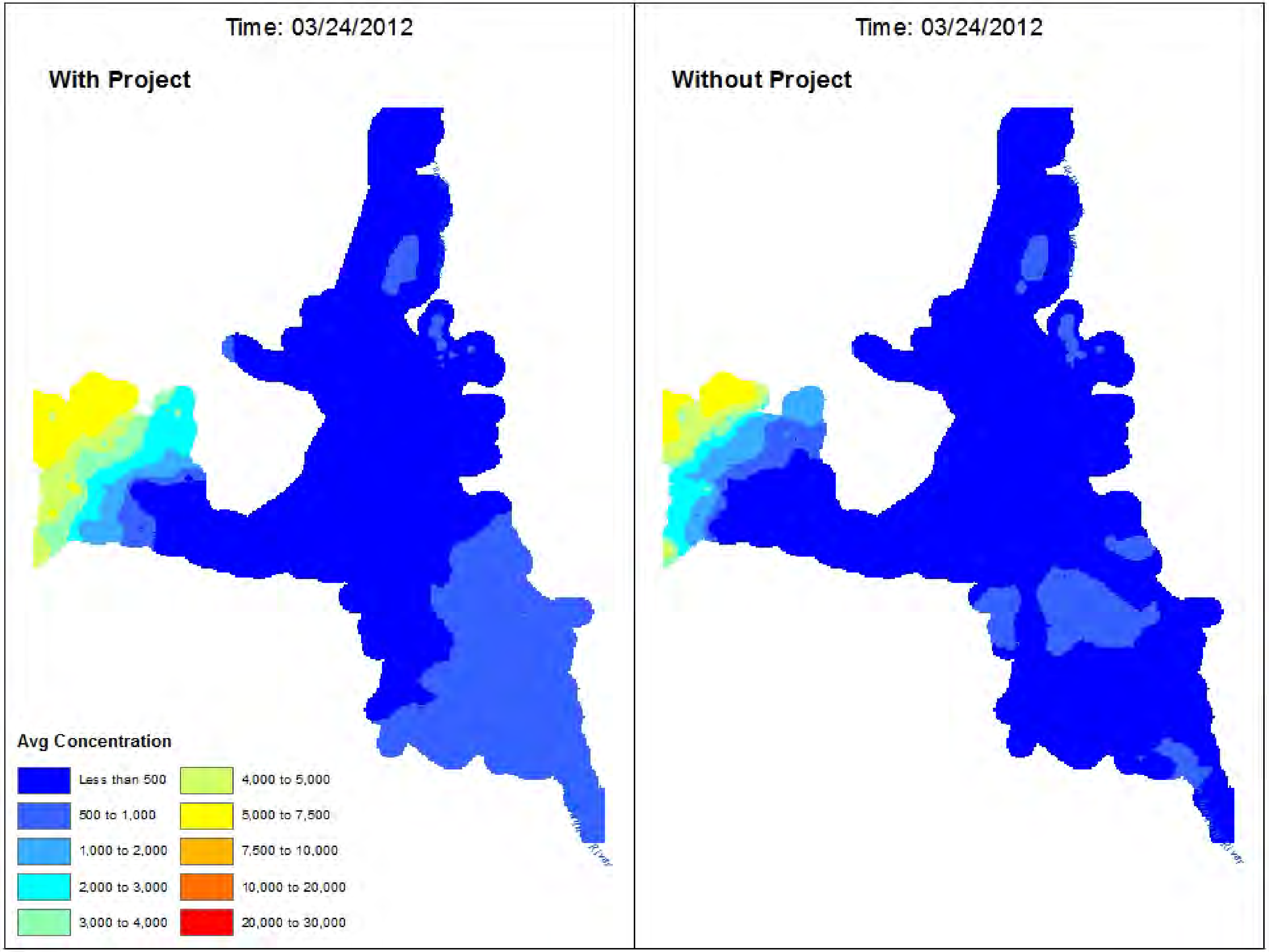


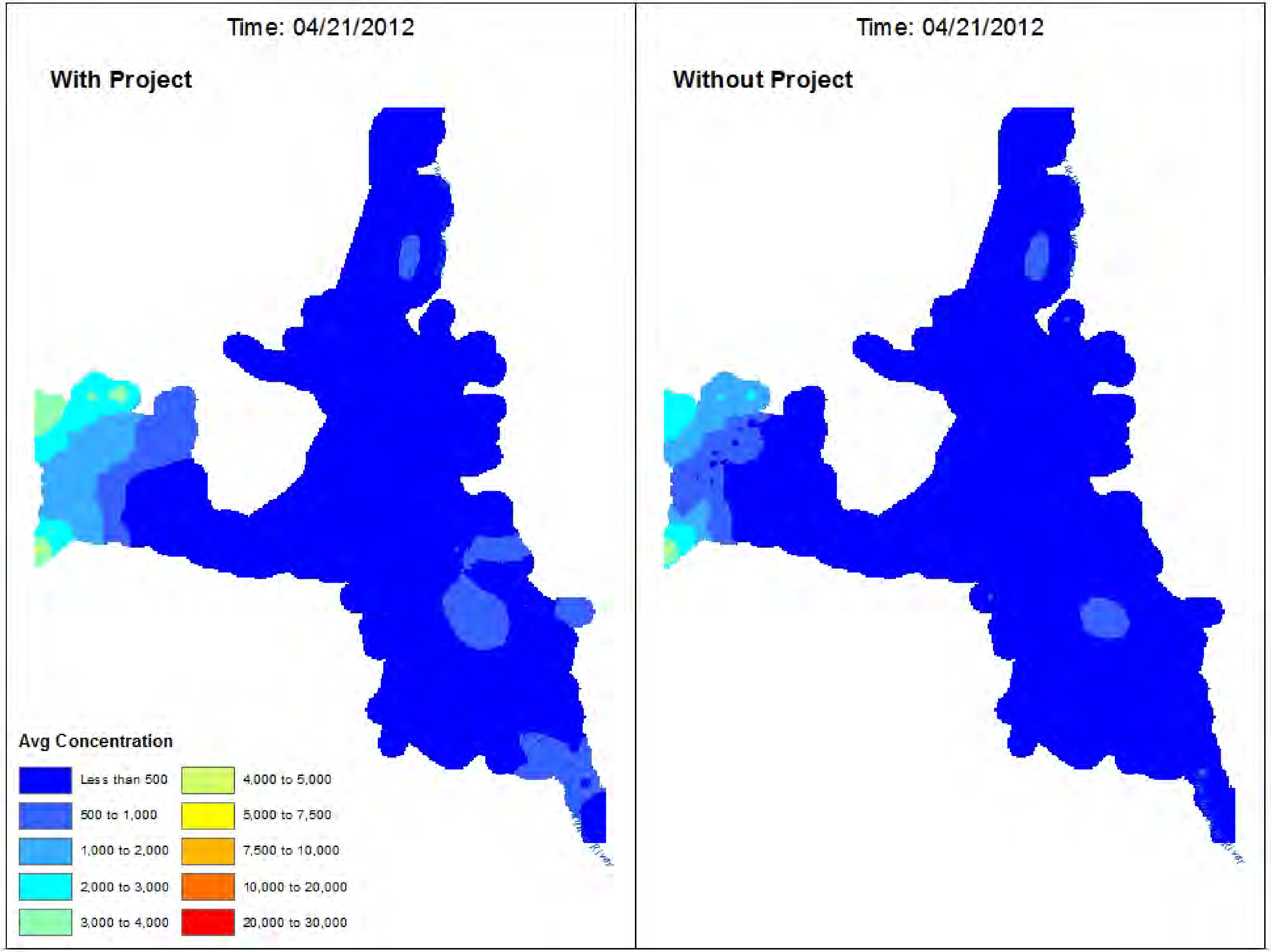
FIGURES 5 TO 52

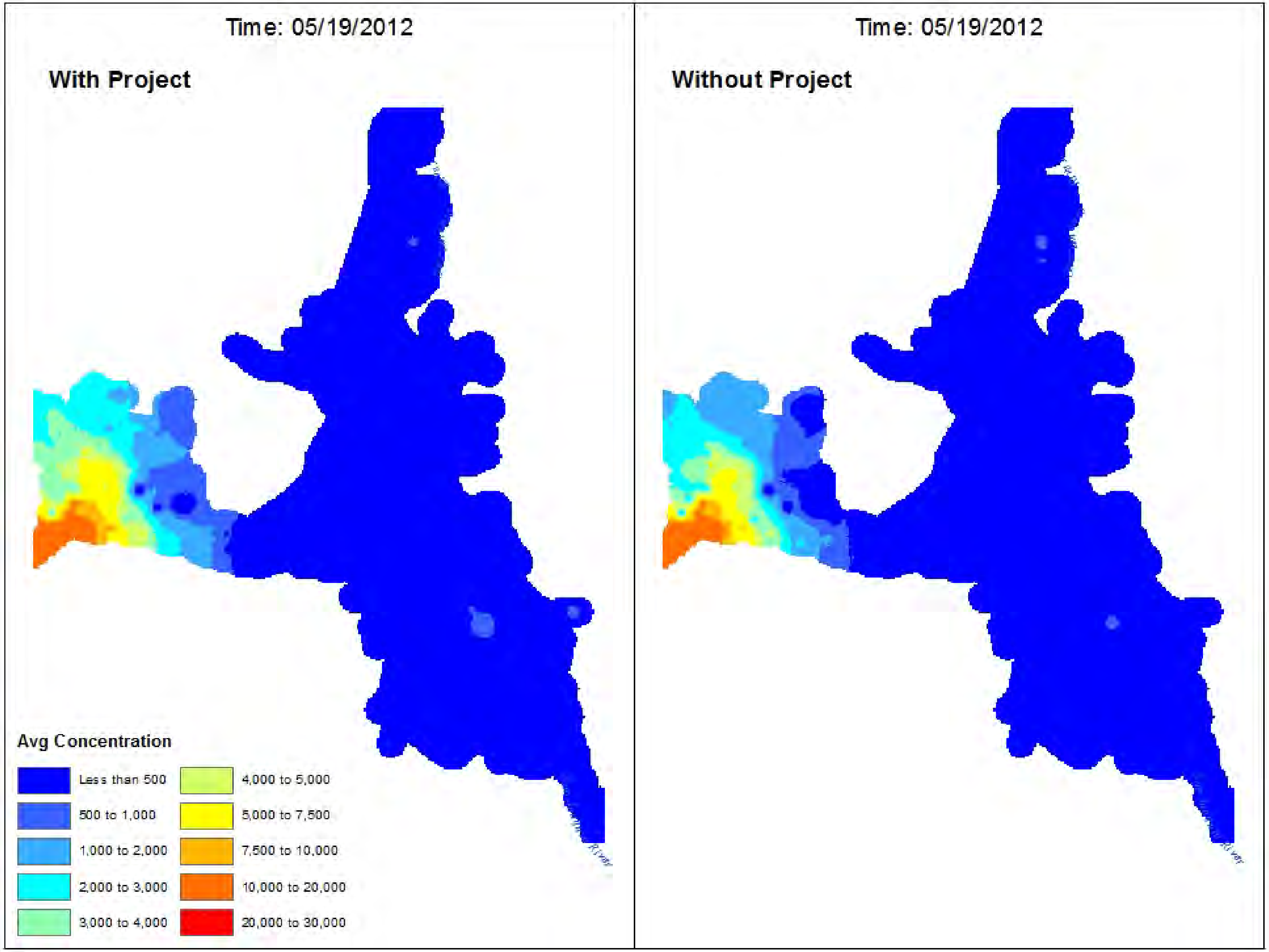
Contour plots of DSM2 electrical conductivity in the Delta on a 4 week timestep for 2011-2015 for With Project conditions (left) and Without Project conditions (right)

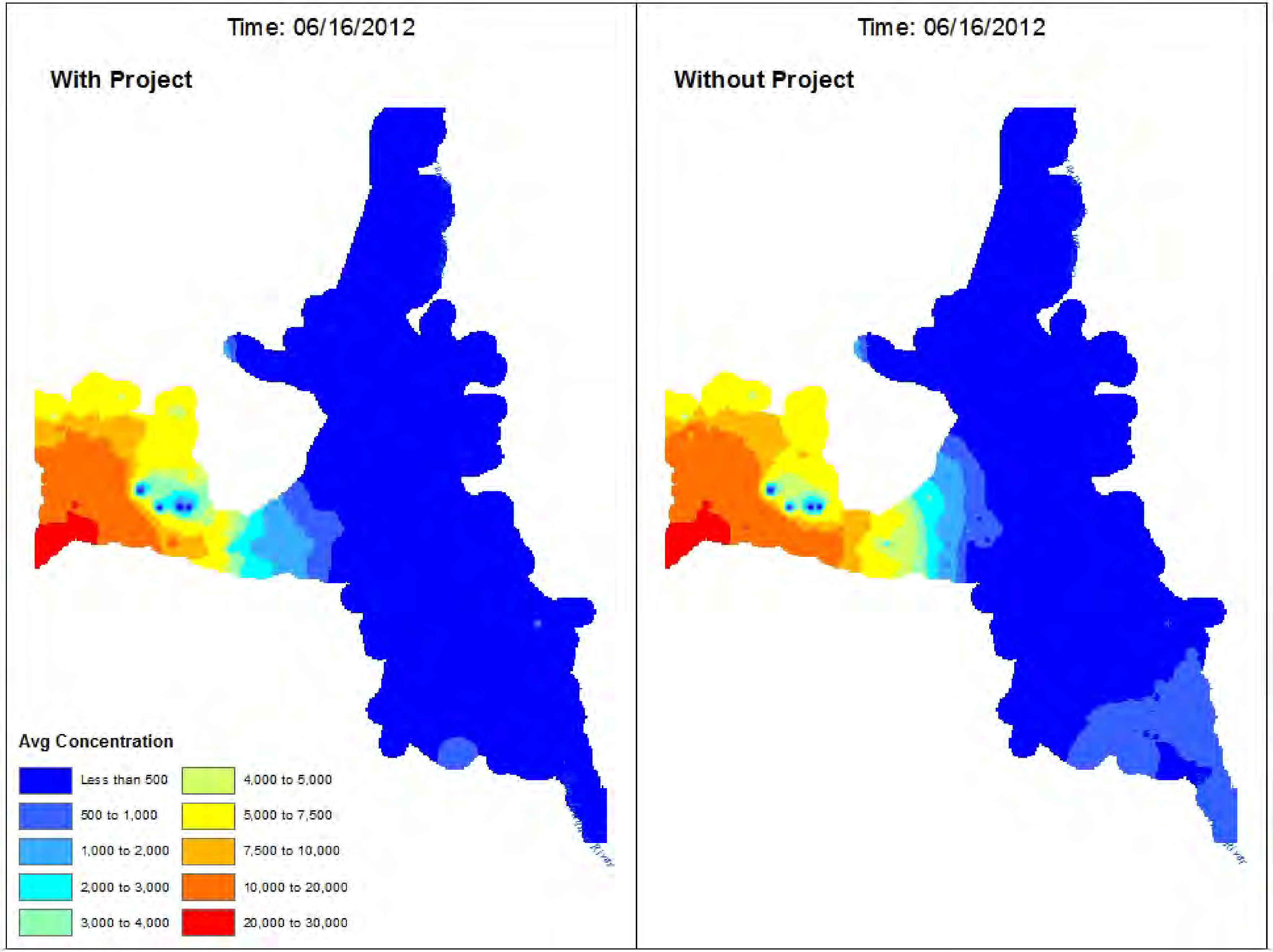

Time: 01/28/2012
With Project
Time: 01/28/2012
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000

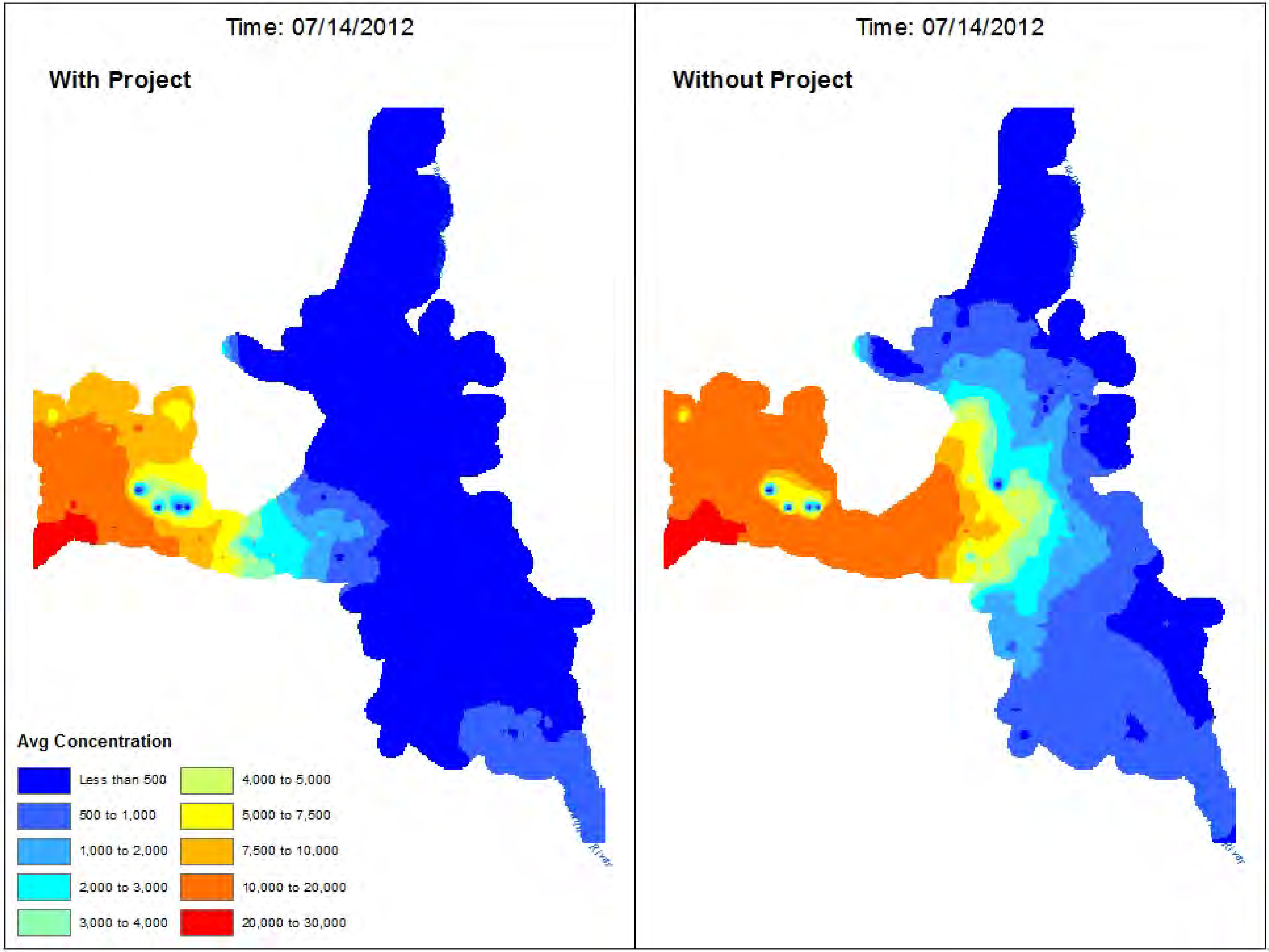

Time: 02/25/2012
With Project
Time: 02/25/2012
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River

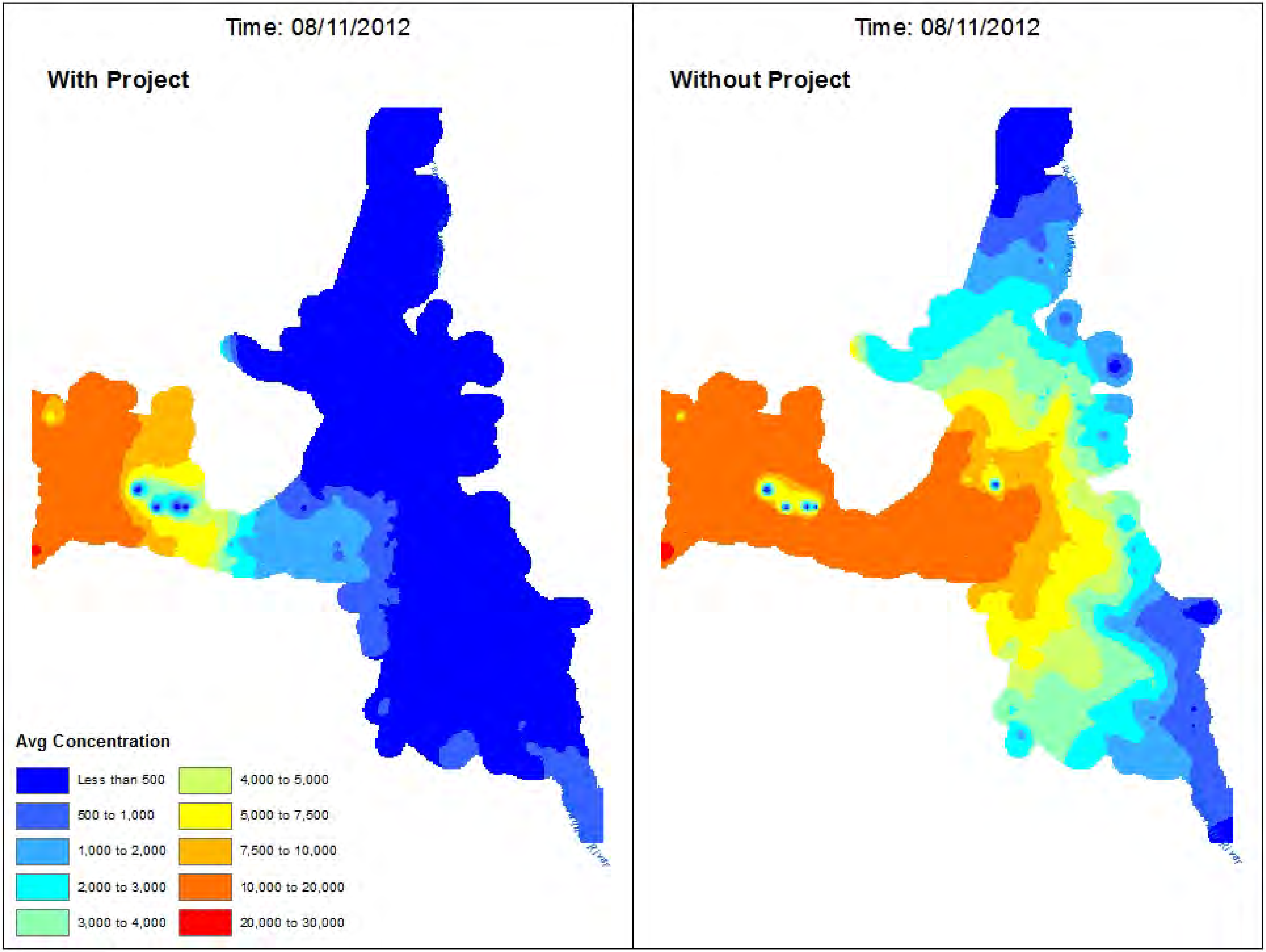

Time: 03/24/2012
With Project
Time: 03/24/2012
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River

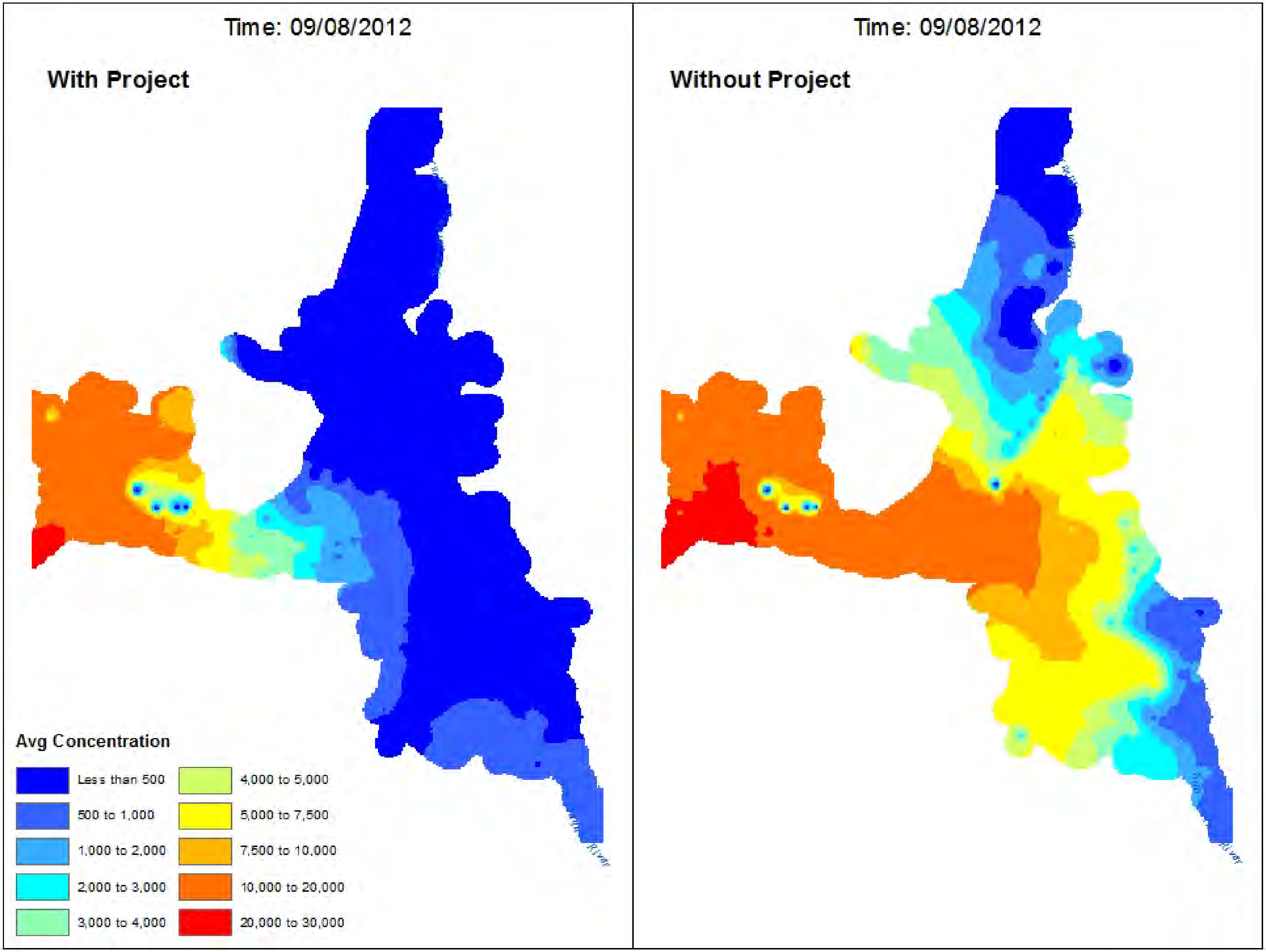

Time: 04/21/2012
With Project
Time: 04/21/2012
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River

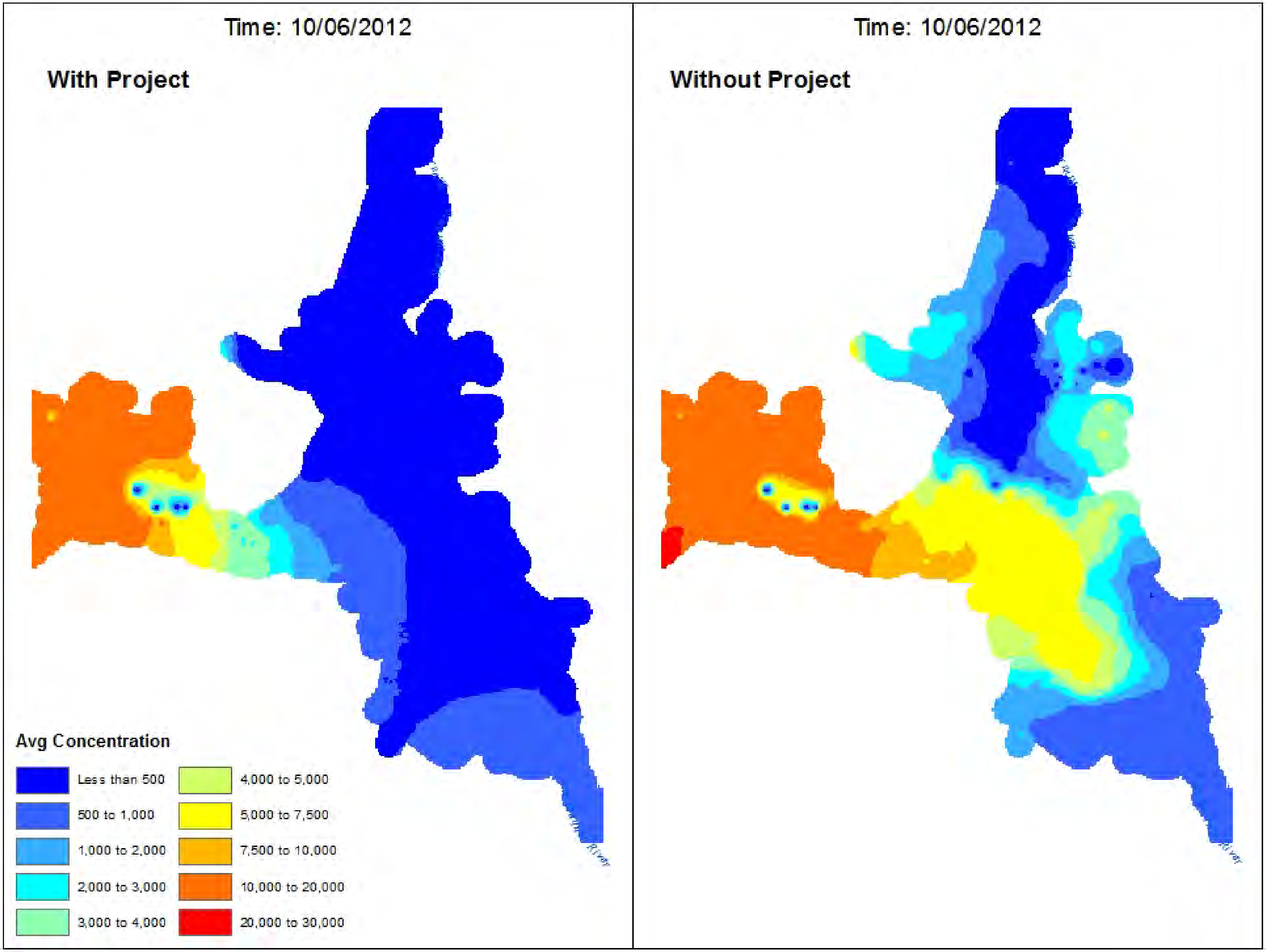

Time: 05/19/2012
With Project
Time: 05/19/2012
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River

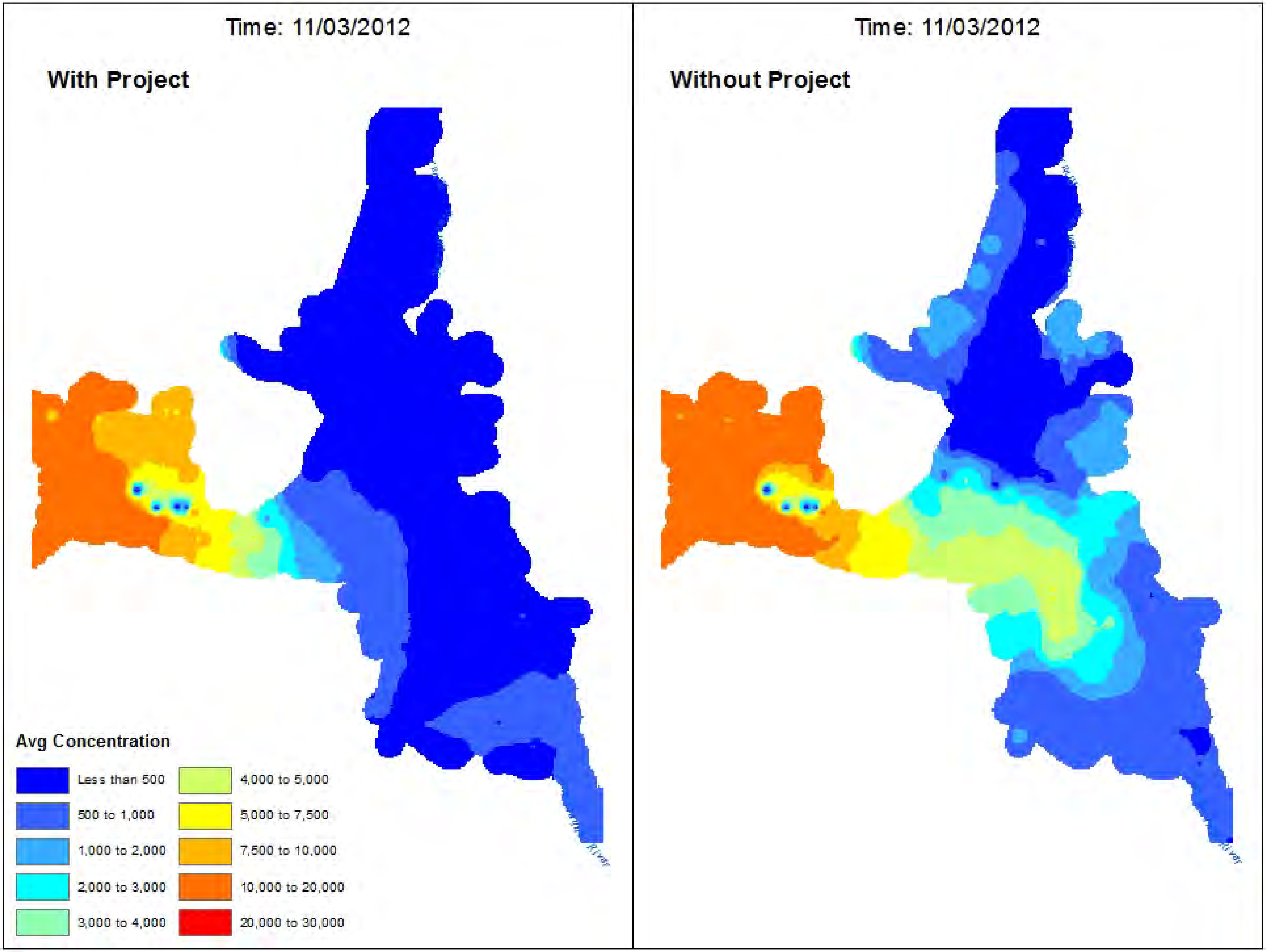

Time: 06/16/2012
With Project
Time: 06/16/2012
Without Project
River
River
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000

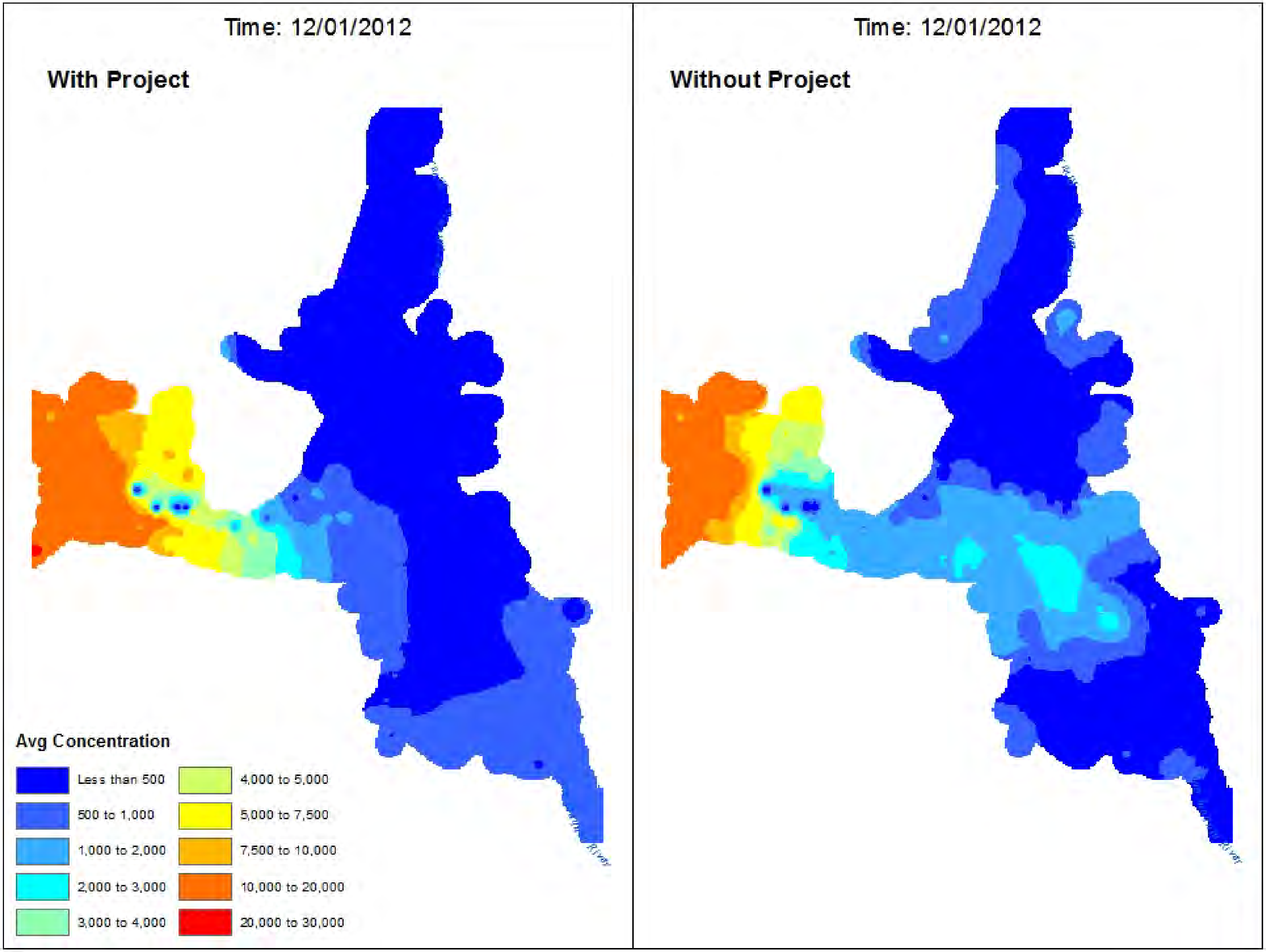

Time: 07/14/2012
With Project
Time: 07/14/2012
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River

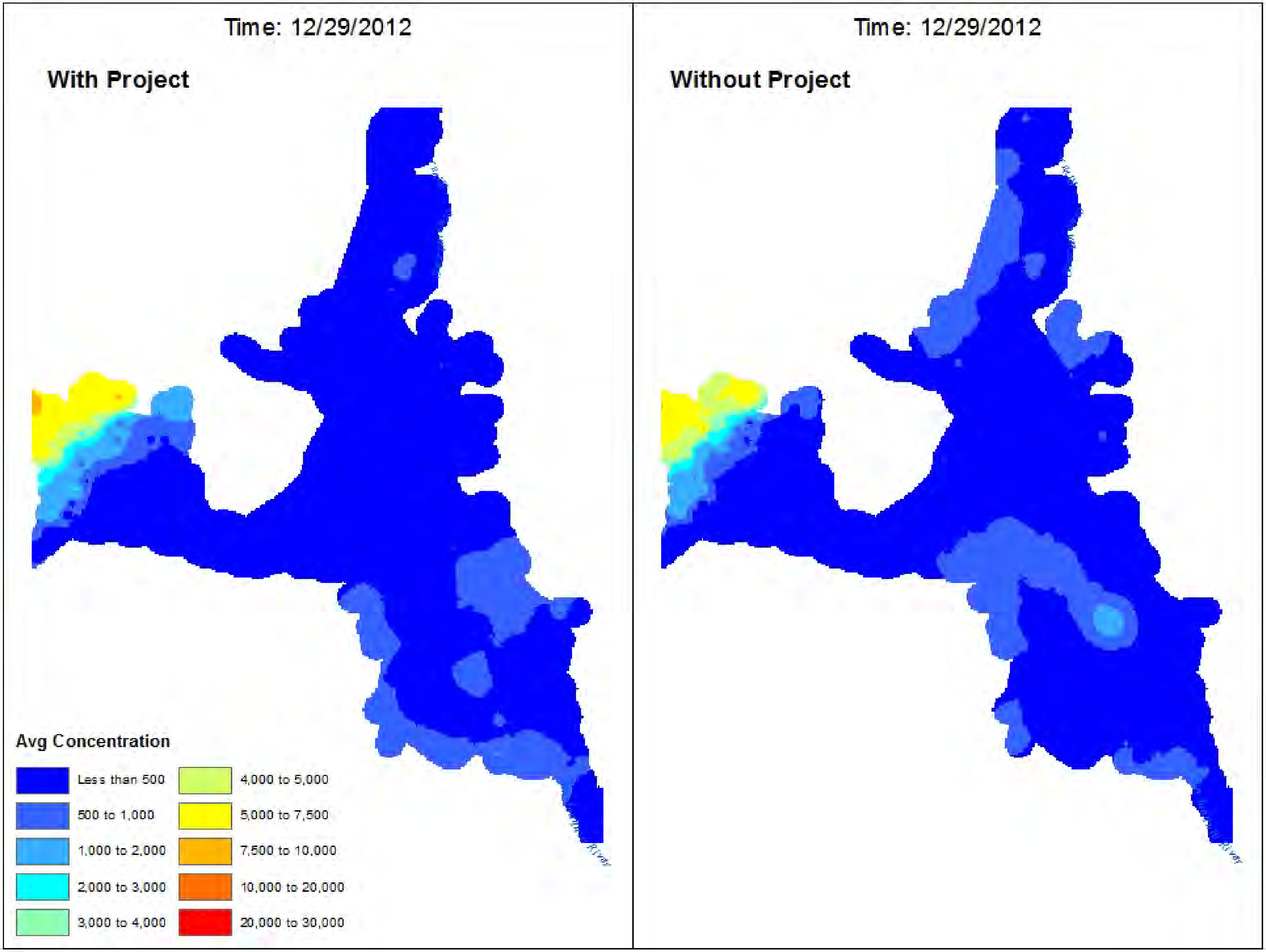

Time: 08/11/2012
With Project
Time: 08/11/2012
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River

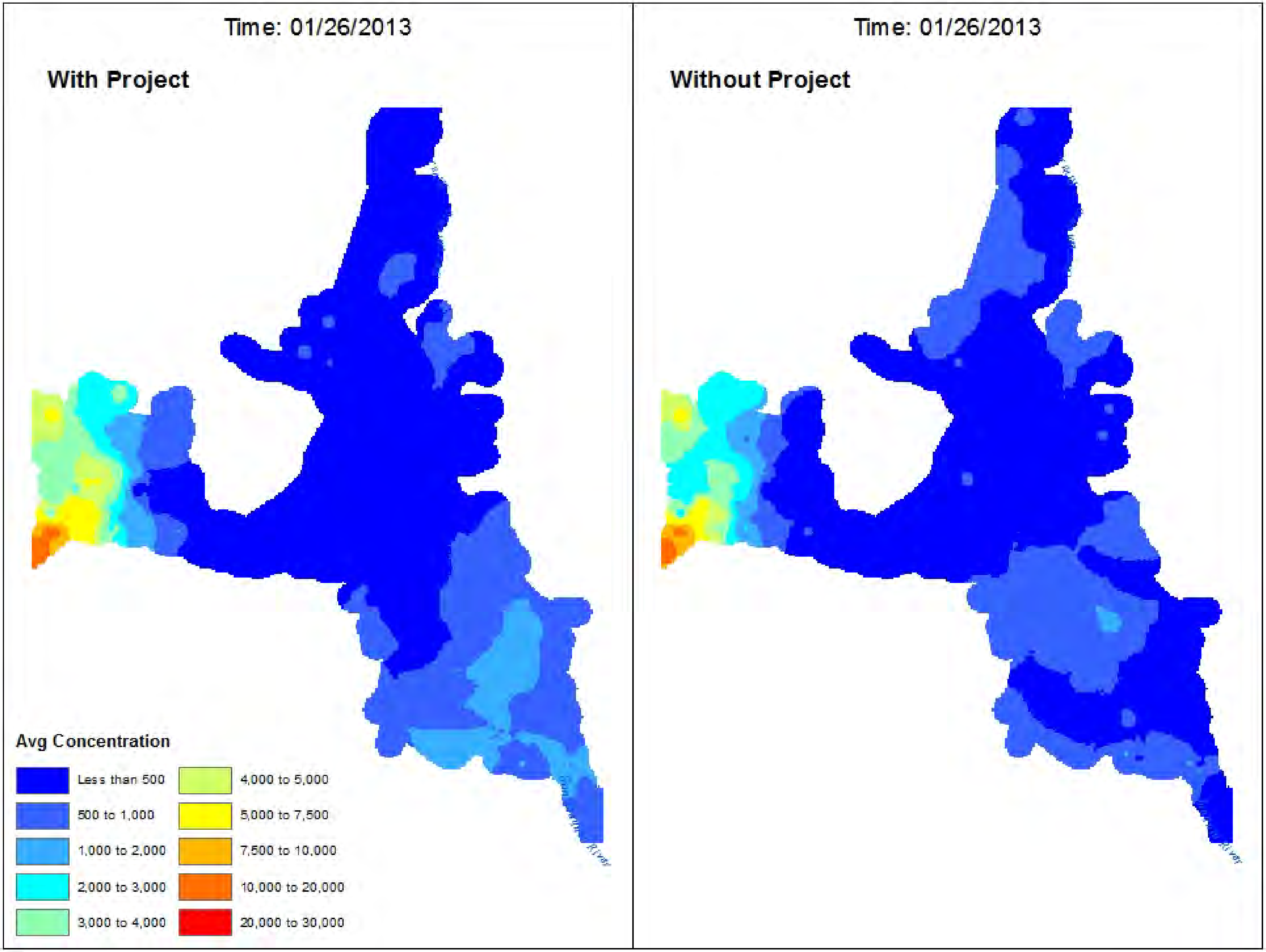

Time: 09/08/2012
With Project
Time: 09/08/2012
Without Project
River
River
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000

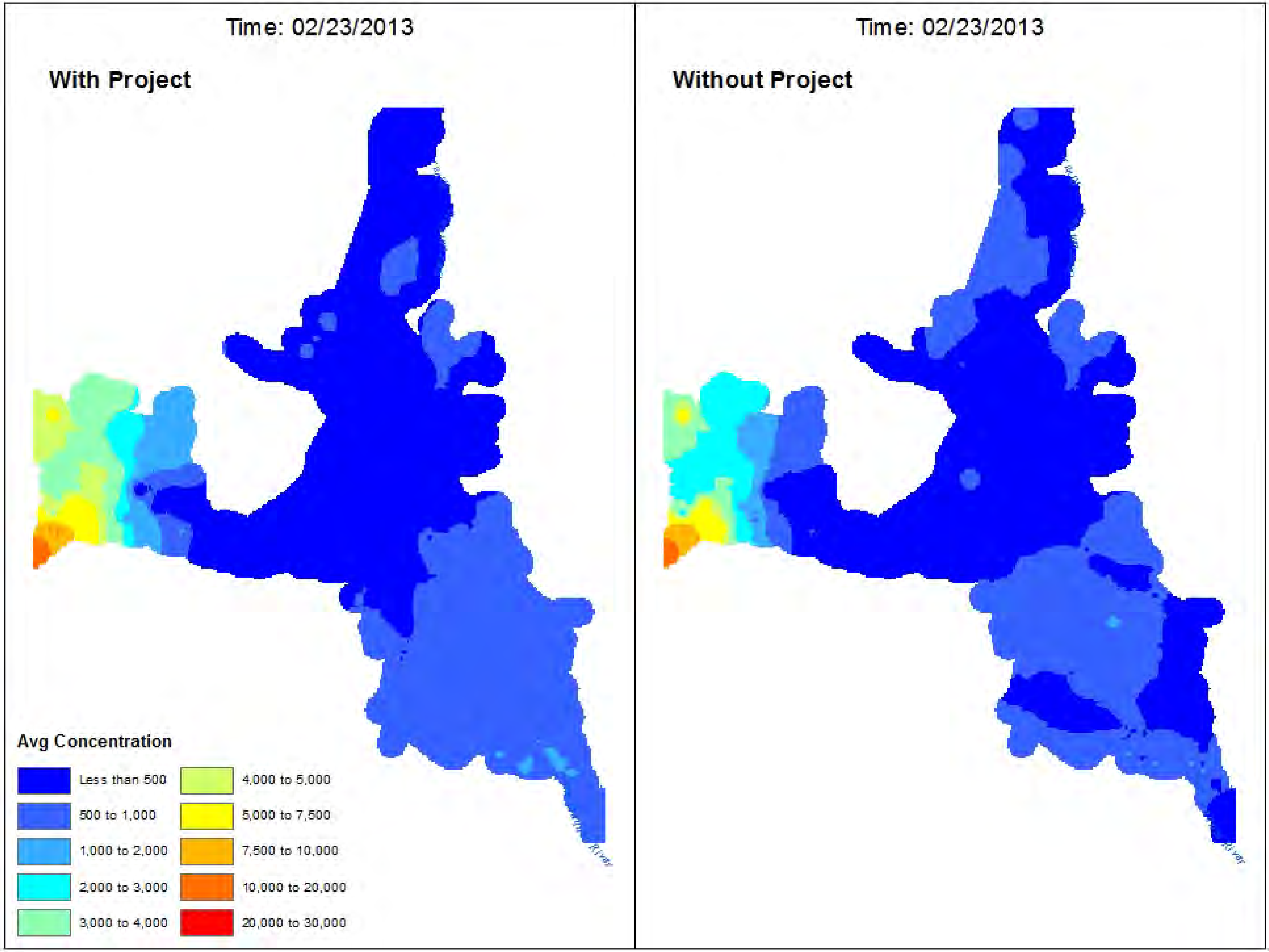

Time: 10/06/2012
With Project
Time: 10/06/2012
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River

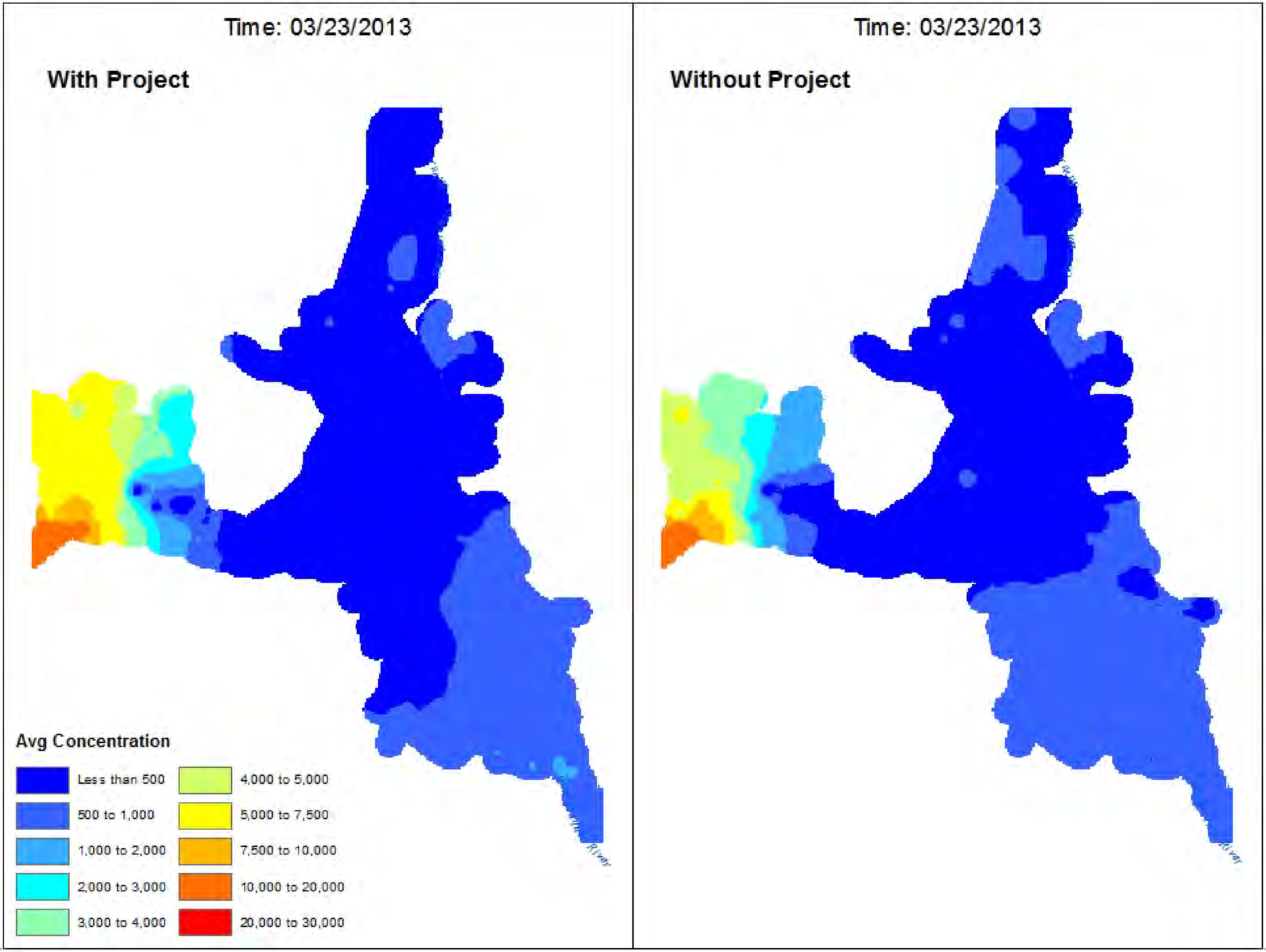

Time: 11/03/2012
With Project
Time: 11/03/2012
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000

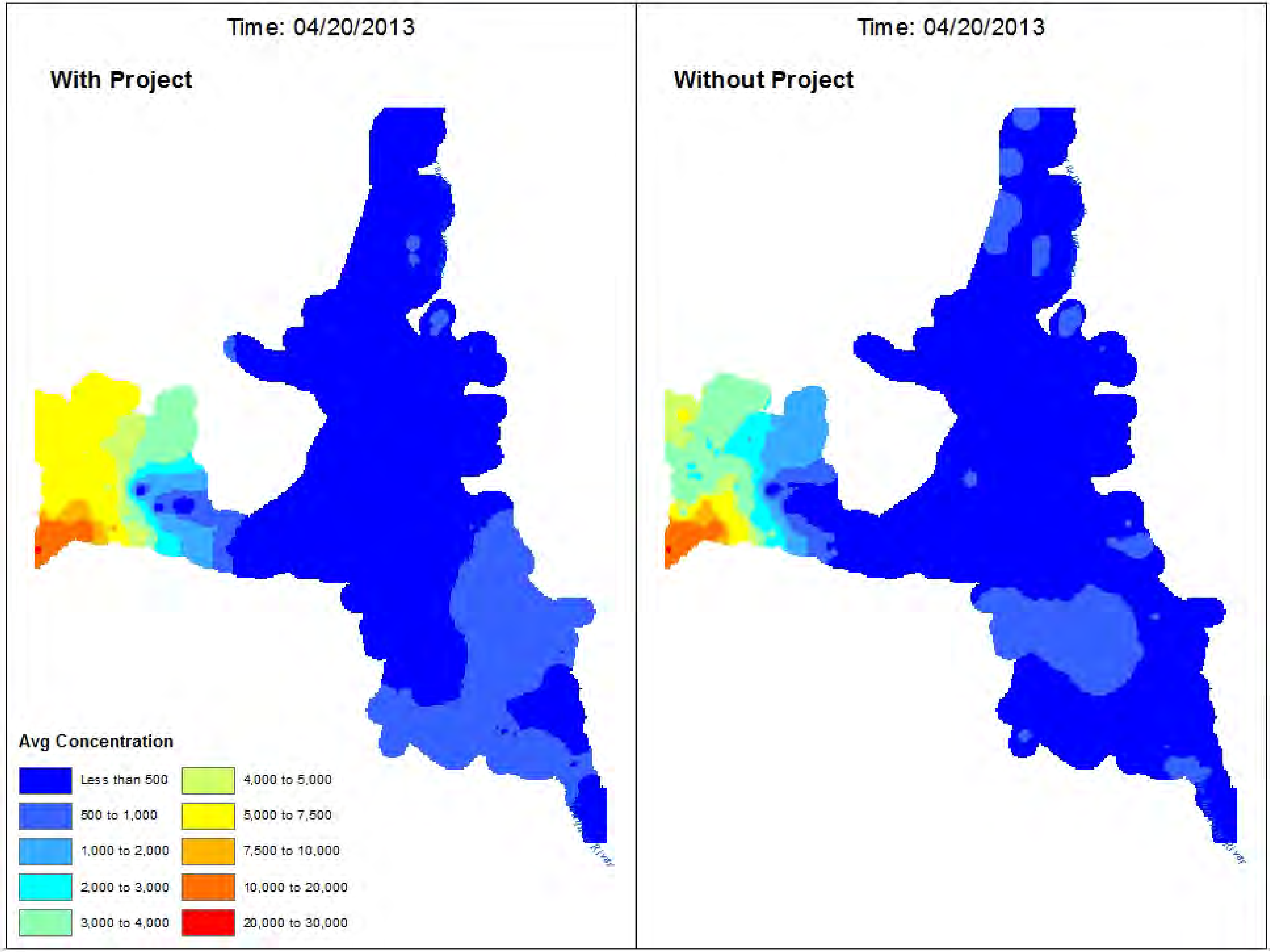

Time: 12/01/2012
With Project
Time: 12/01/2012
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River

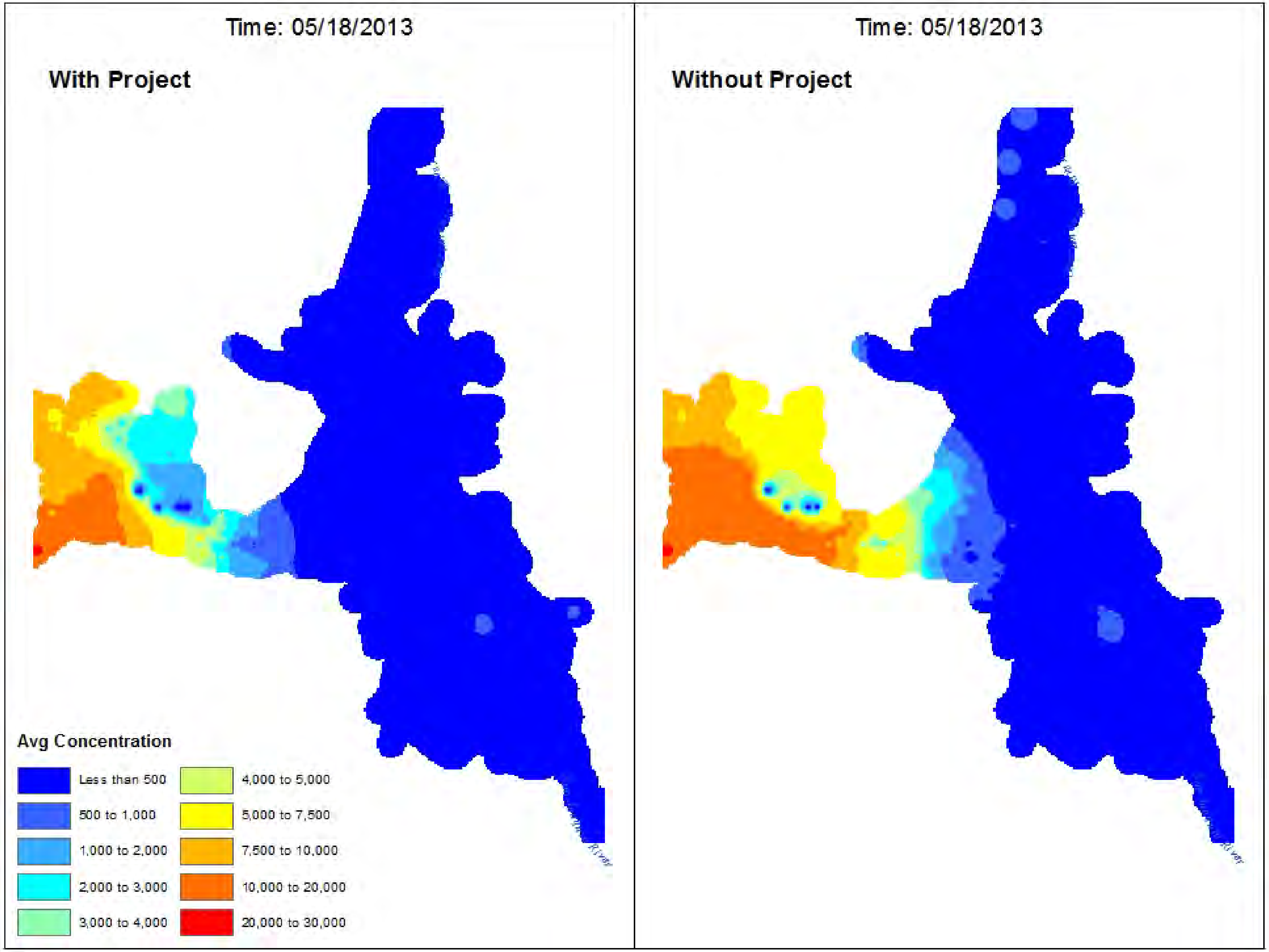

Time: 12/29/2012
With Project
Time: 12/29/2012
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River

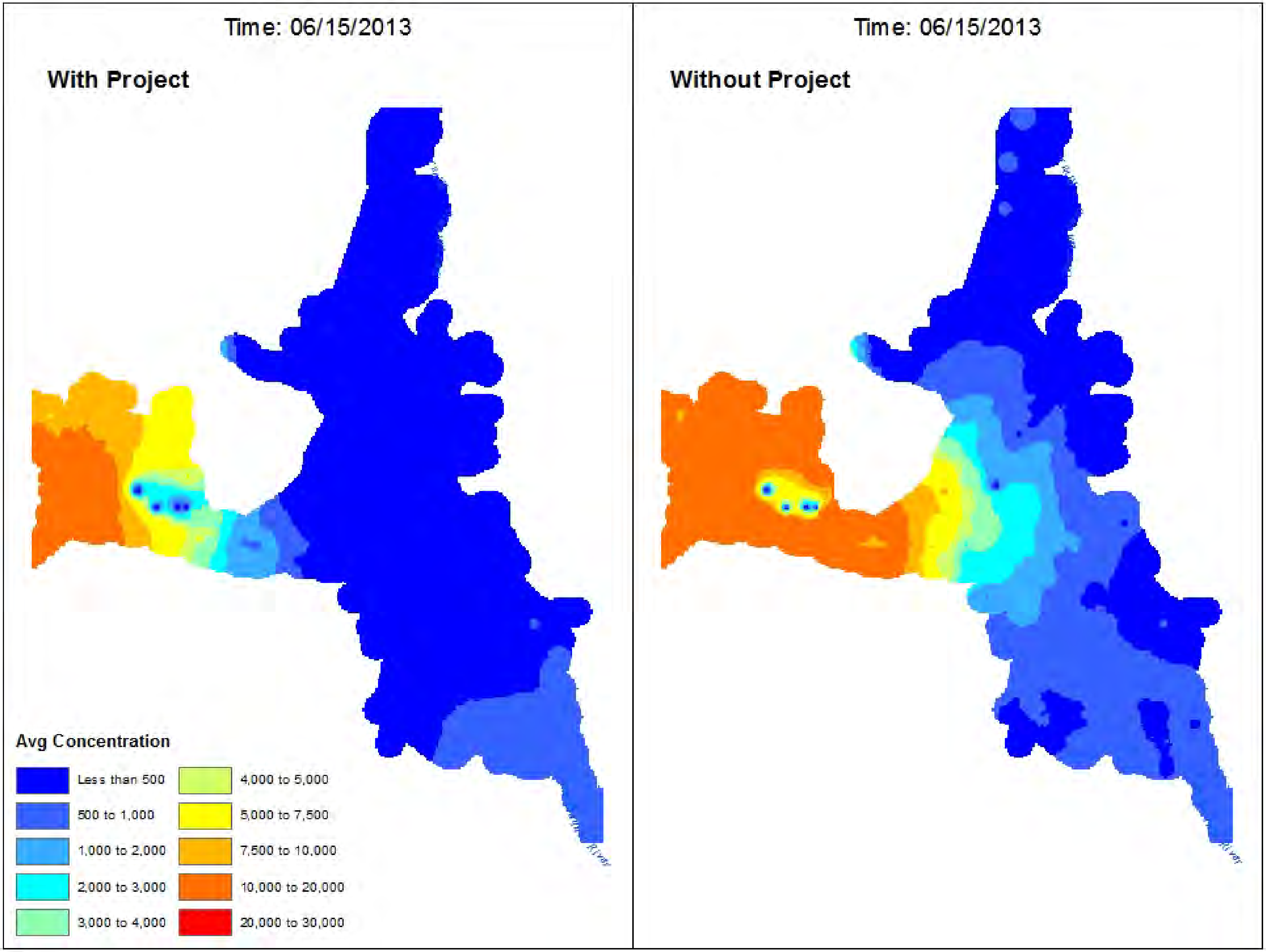

Time: 01/26/2013
With Project
Time: 01/26/2013
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River

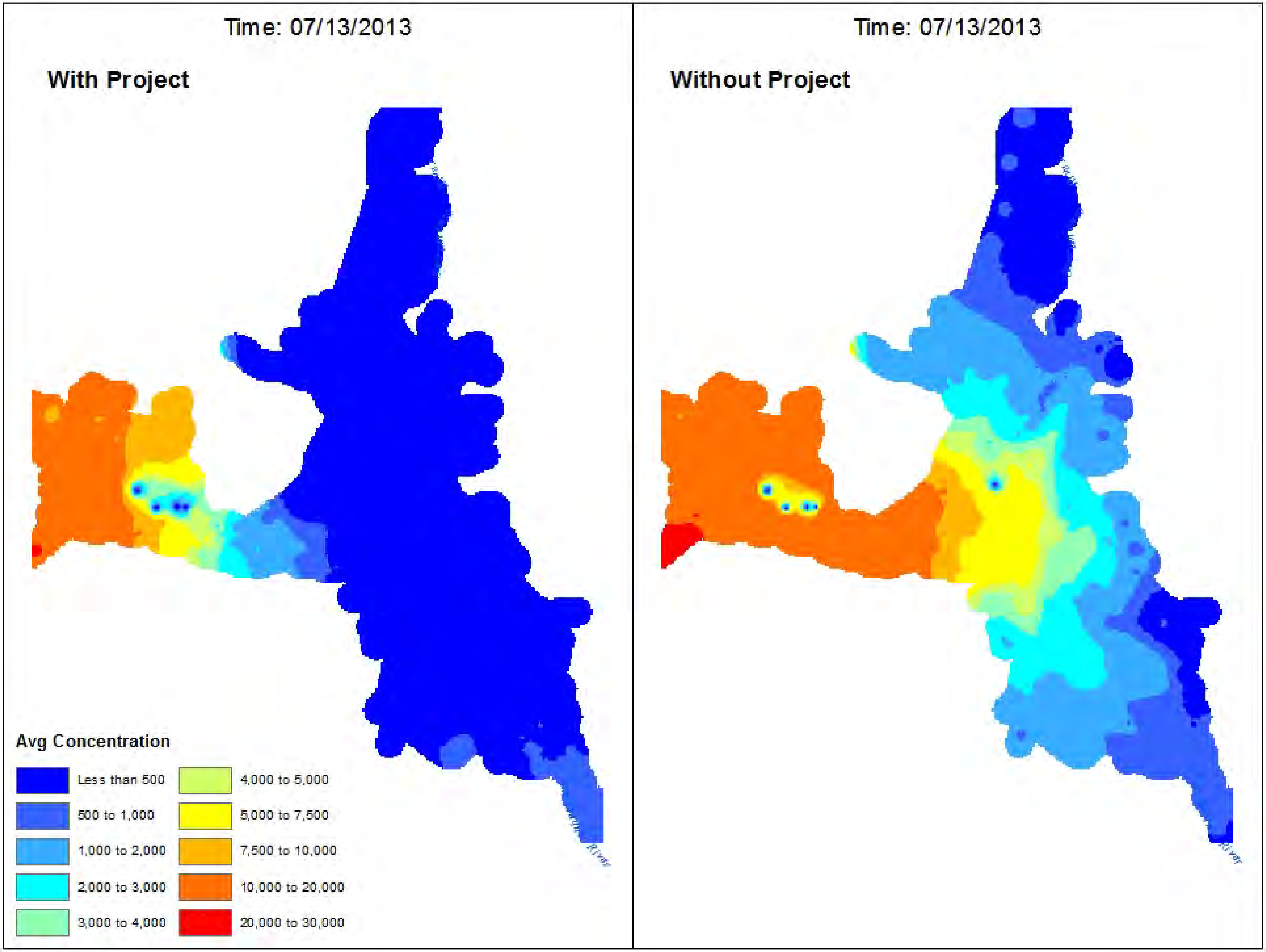

Time: 02/23/2013
With Project
Time: 02/23/2013
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River

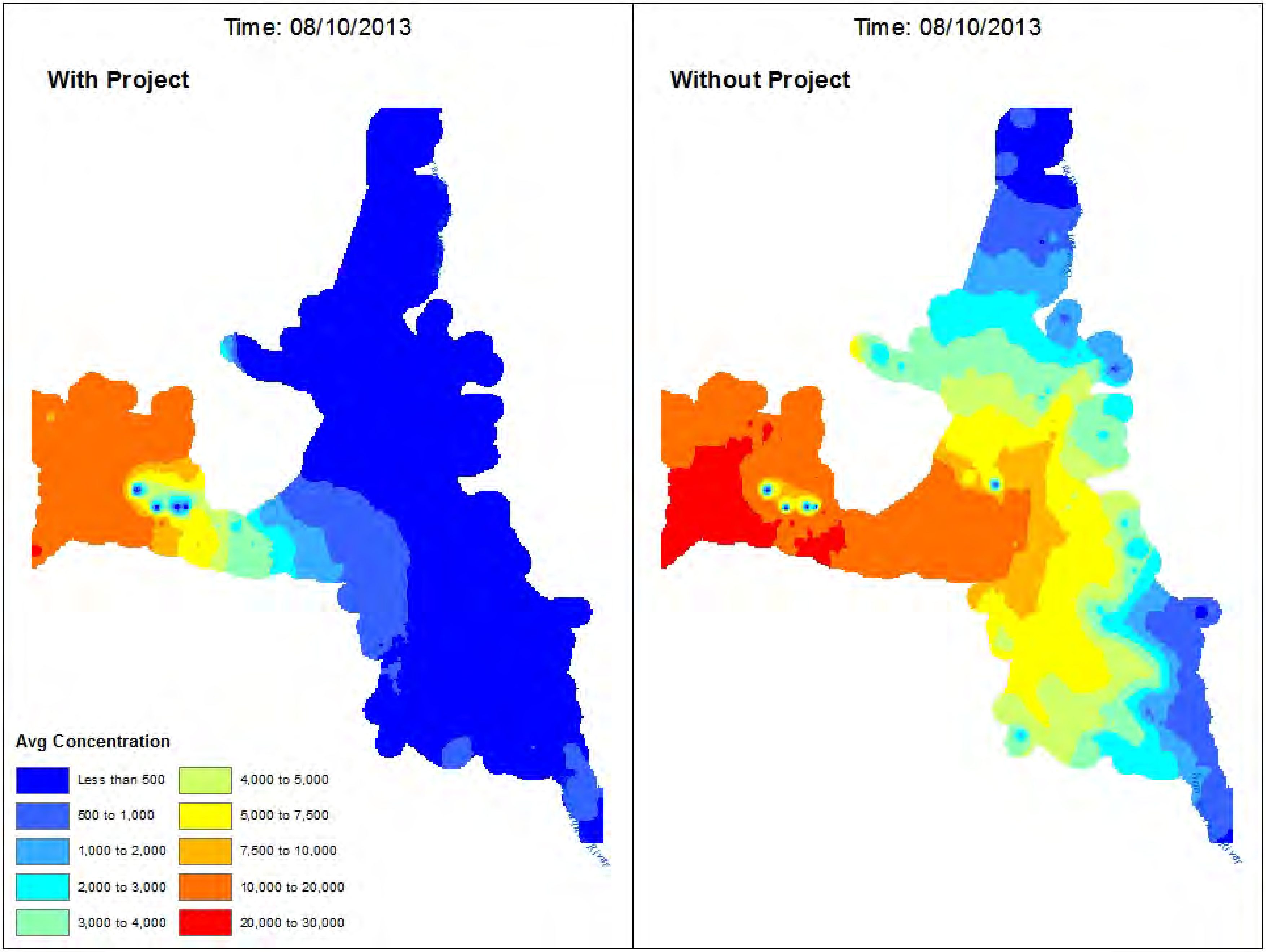

Time: 03/23/2013
With Project
Time: 03/23/2013
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River

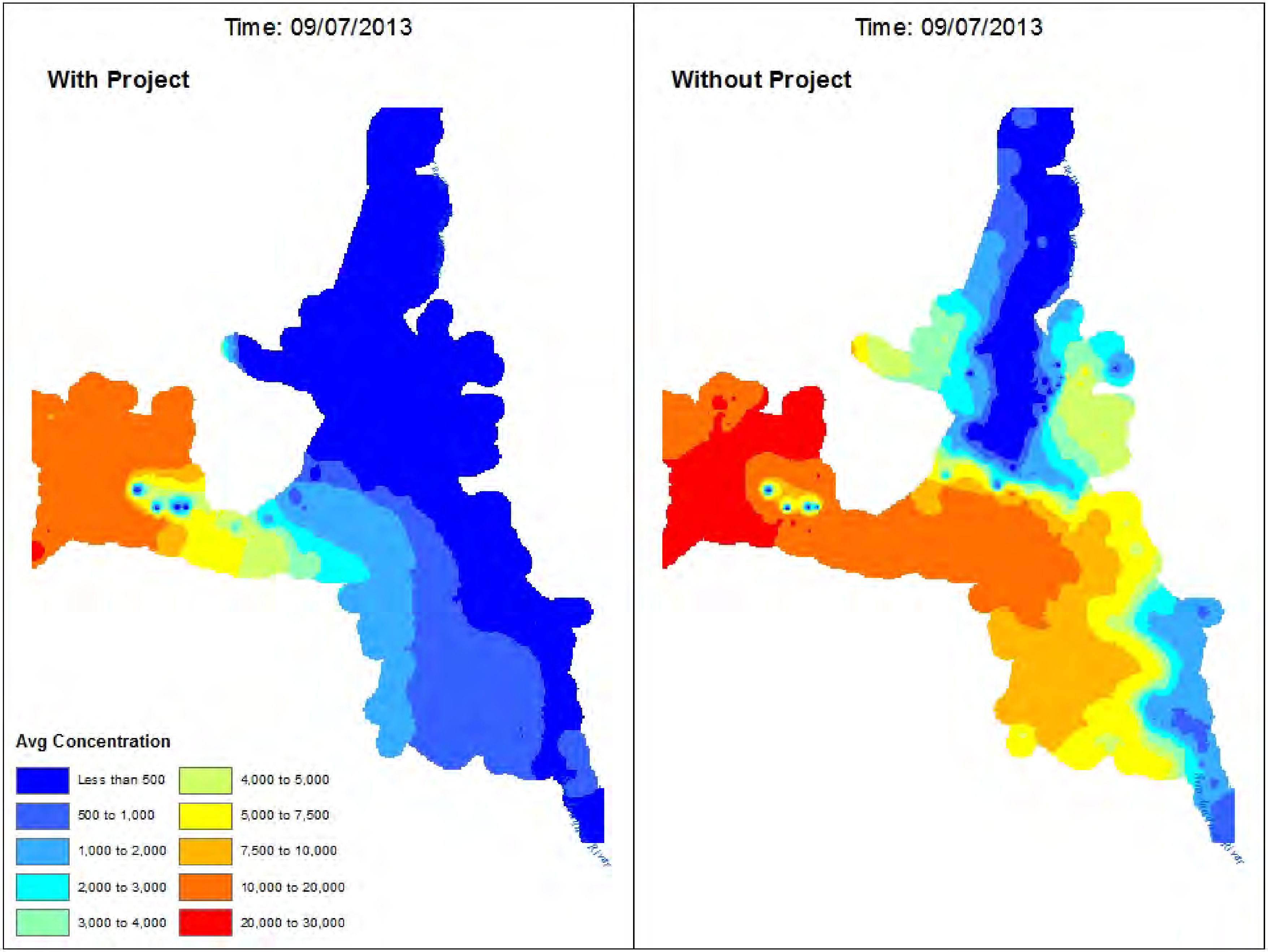

Time: 04/20/2013
With Project
Time: 04/20/2013
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River

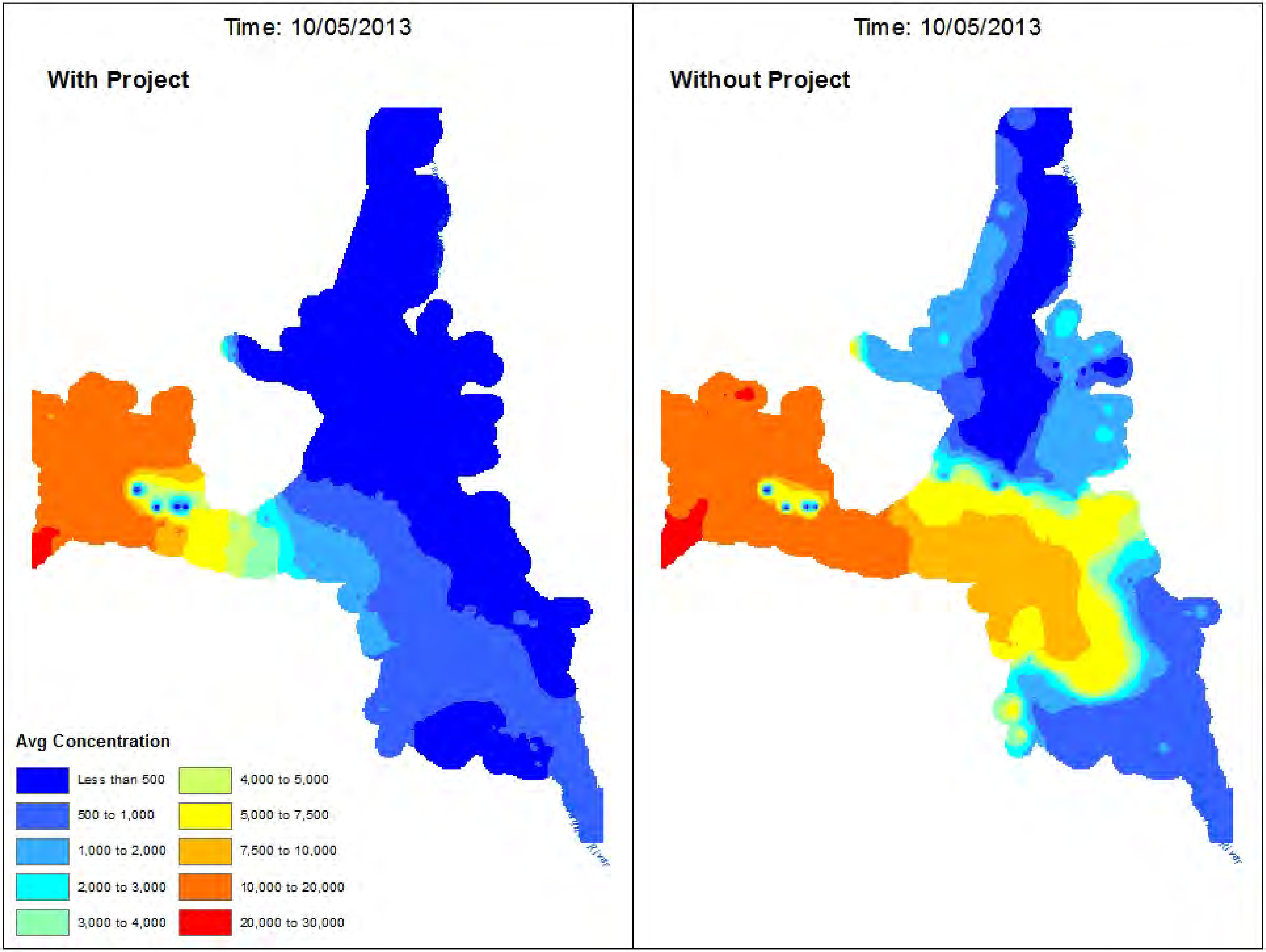

Time: 05/18/2013
With Project
Time: 05/18/2013
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River

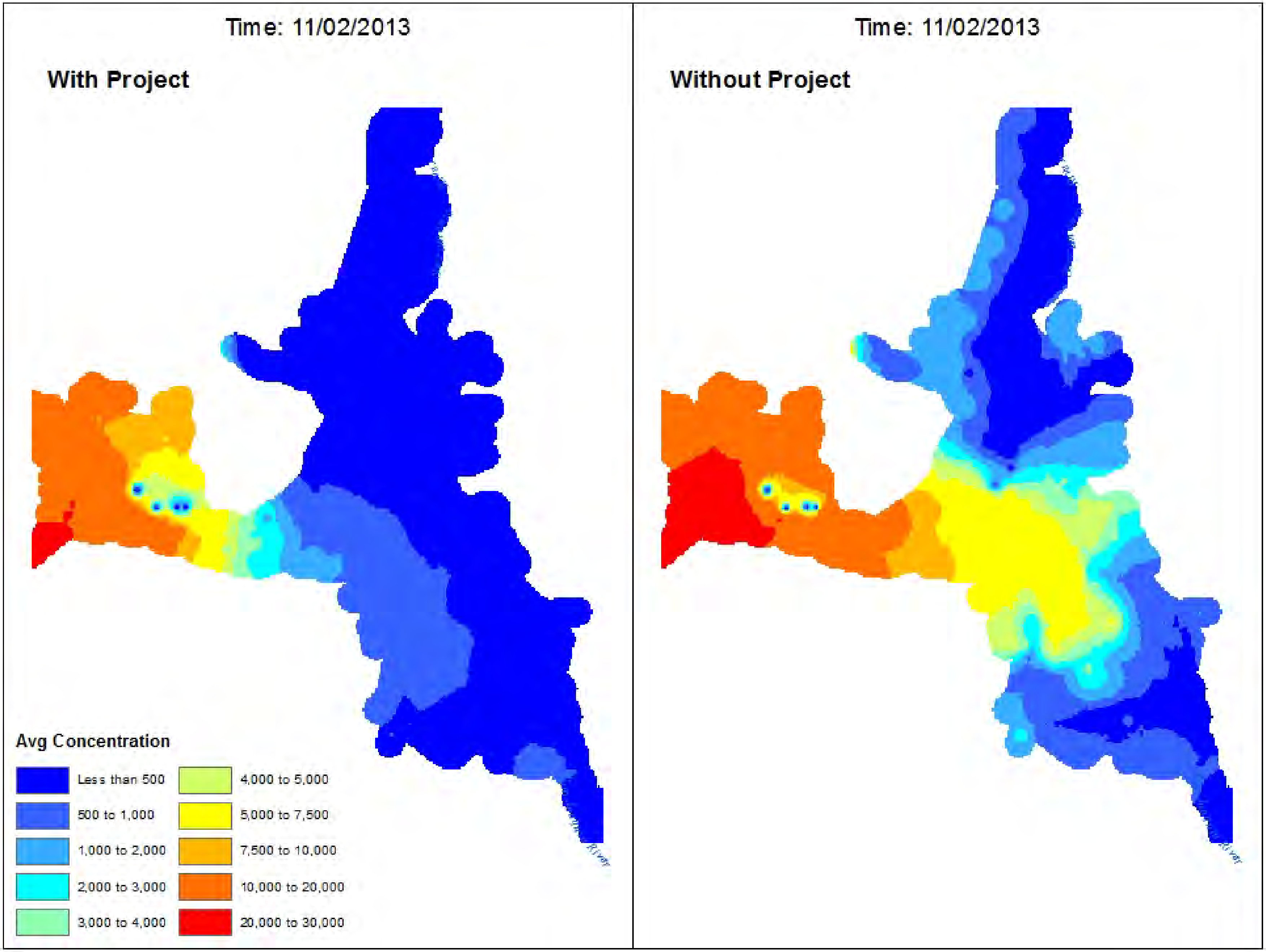

Time: 06/15/2013
With Project
Time: 06/15/2013
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River

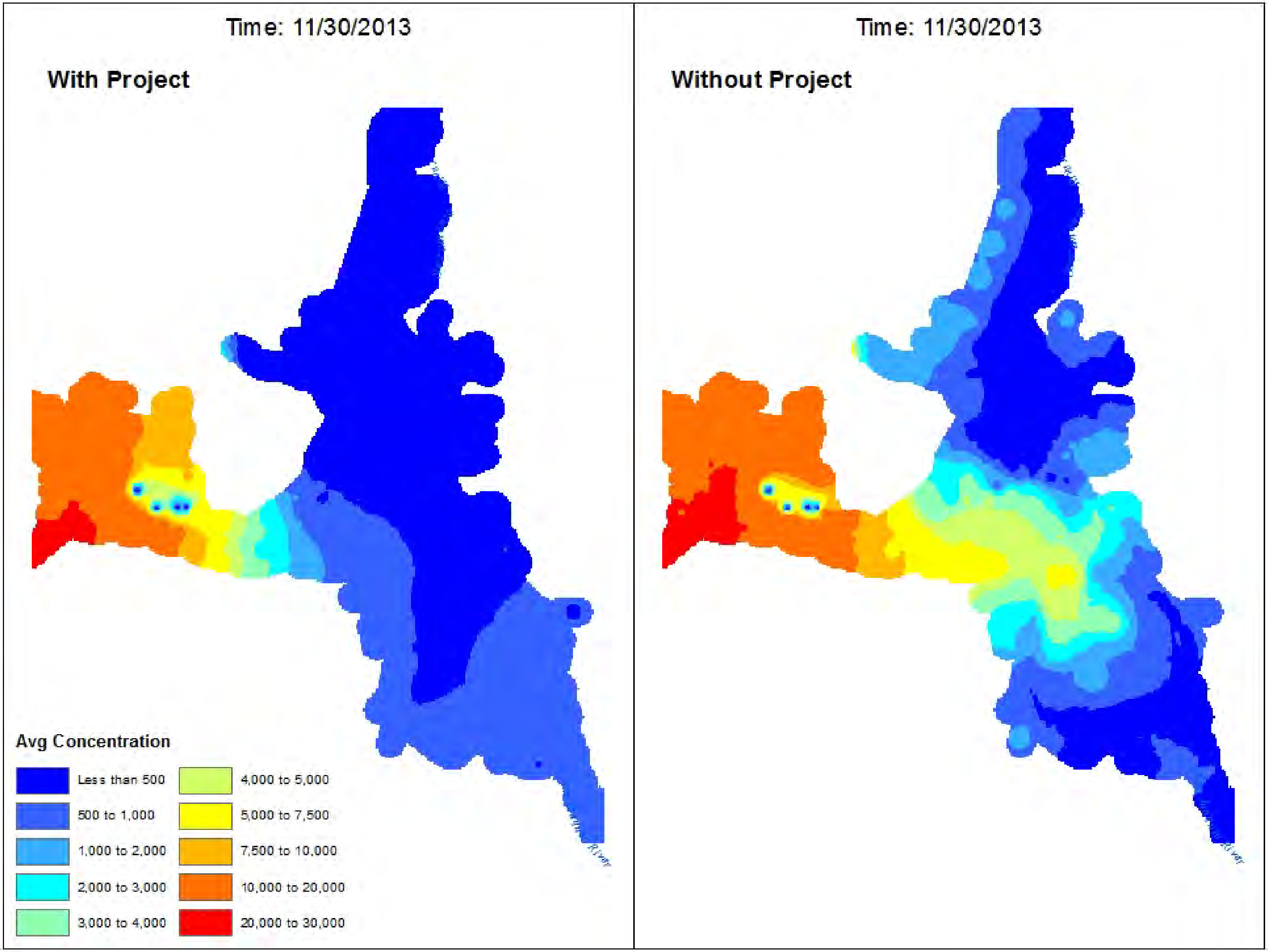

Time: 07/13/2013
With Project
Time: 07/13/2013
Without Project
River
River
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000

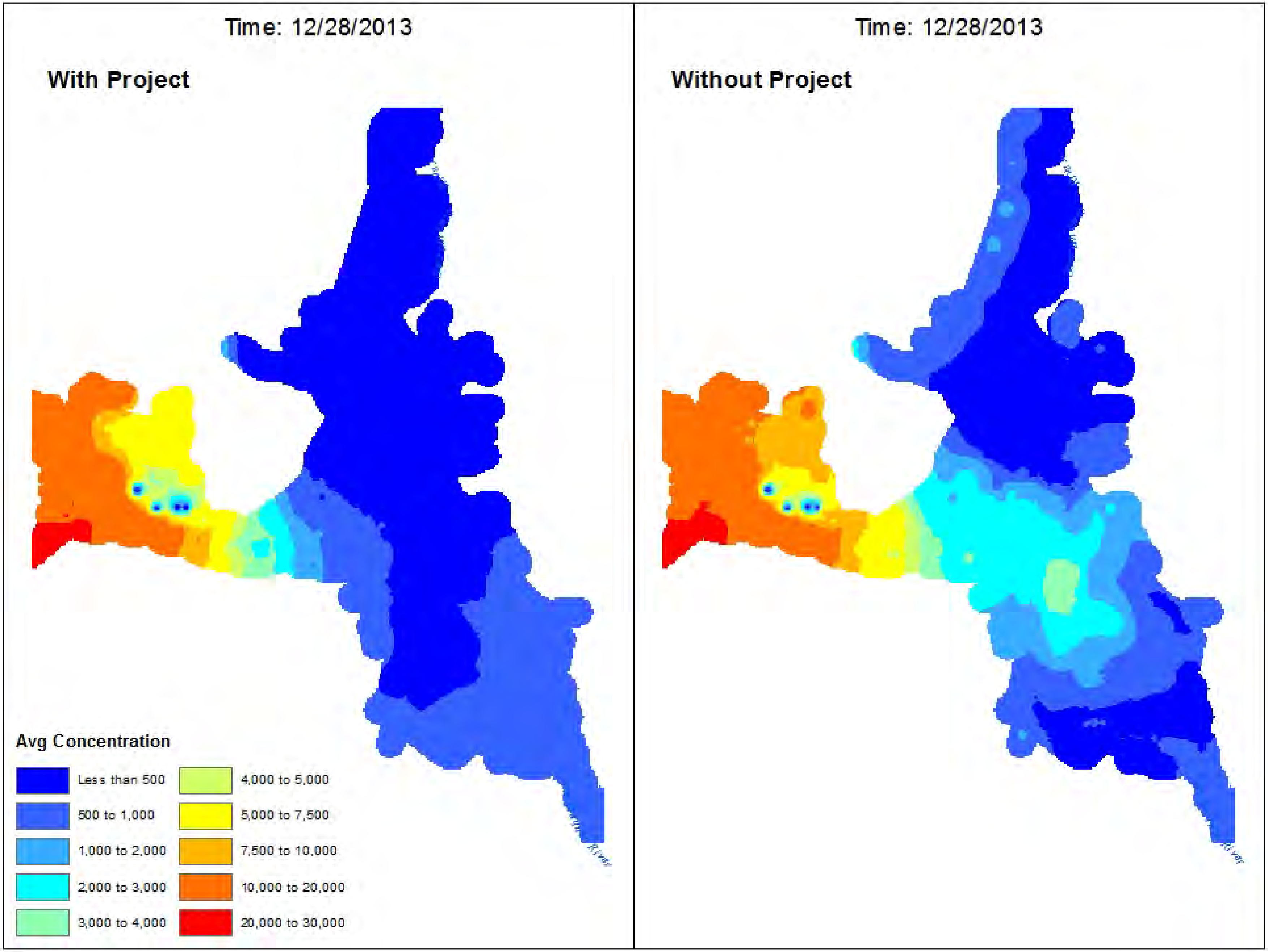

Time: 08/10/2013
With Project
Time: 08/10/2013
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River

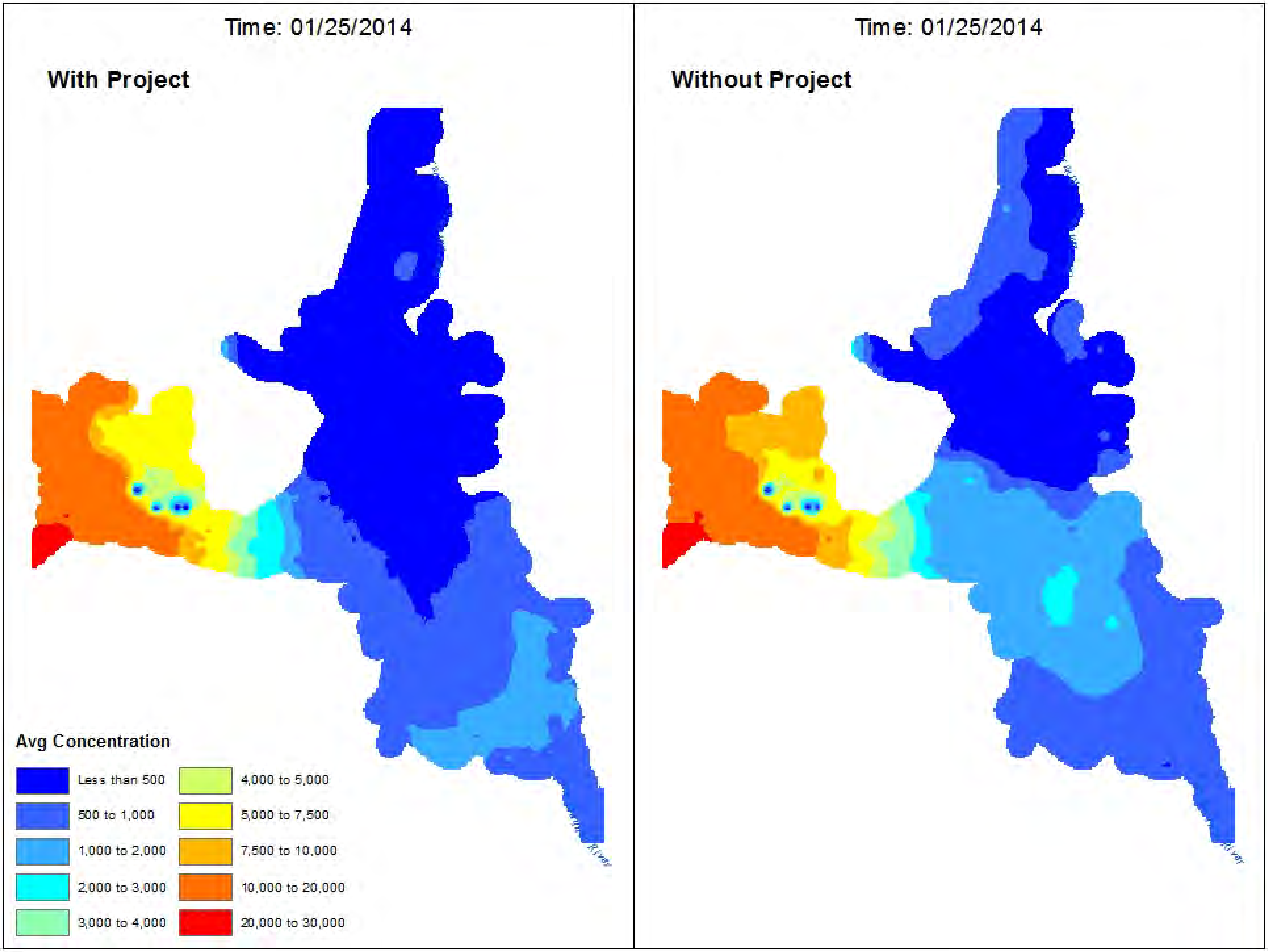

Time: 09/07/2013
With Project
Time: 09/07/2013
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River

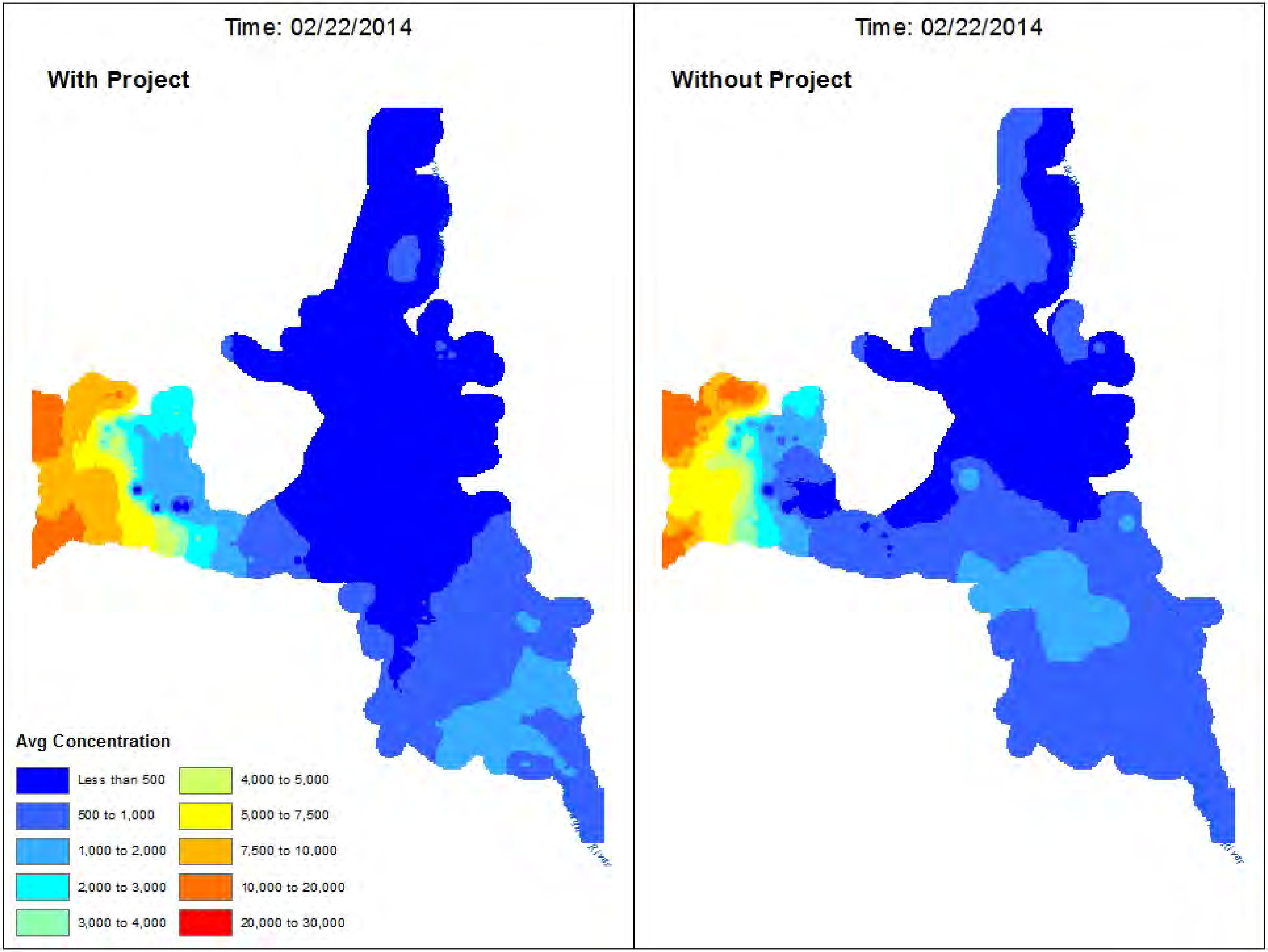

Time: 10/05/2013
With Project
Time: 10/05/2013
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River

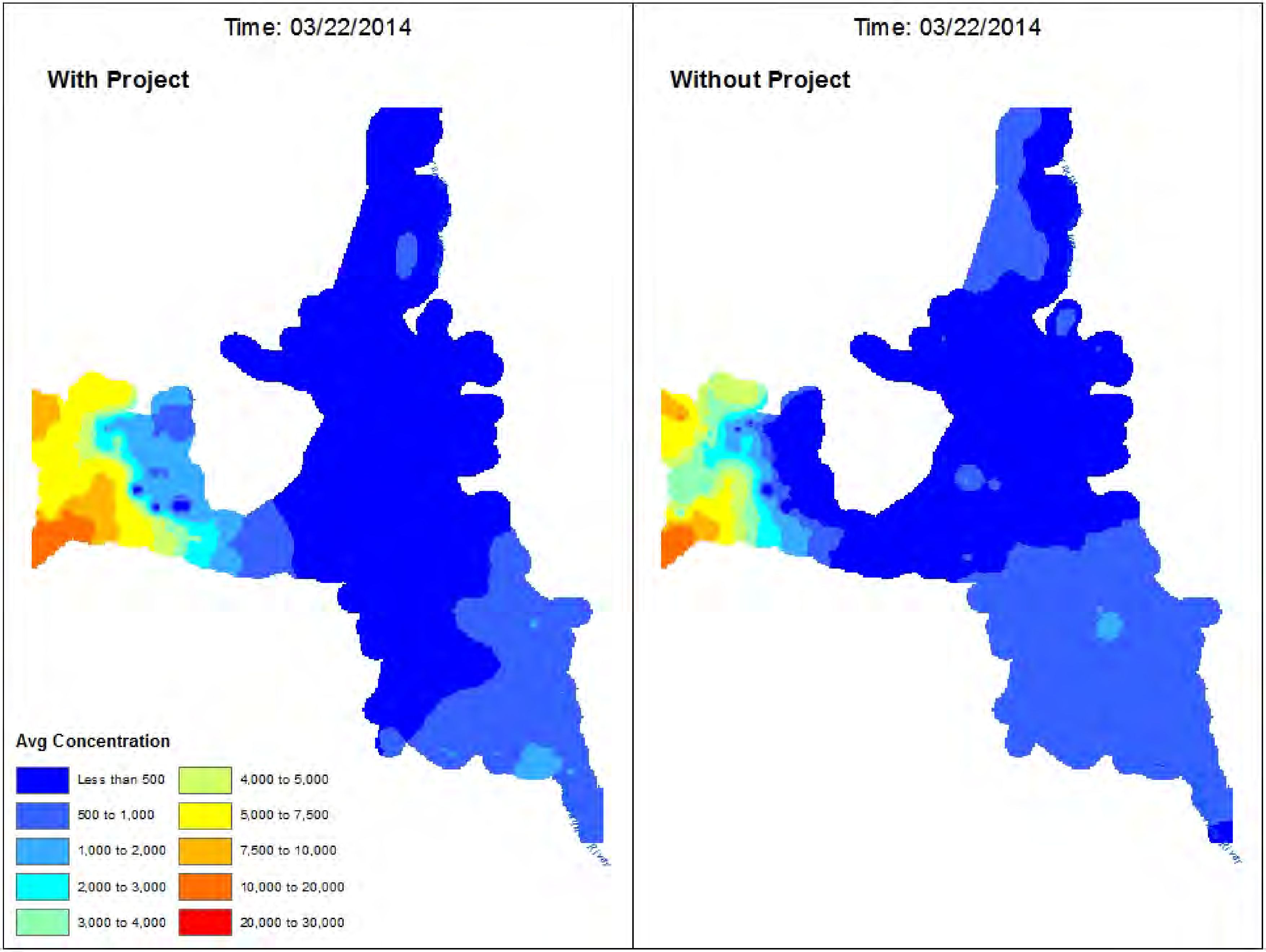

Time: 11/02/2013
With Project
Time: 11/02/2013
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River

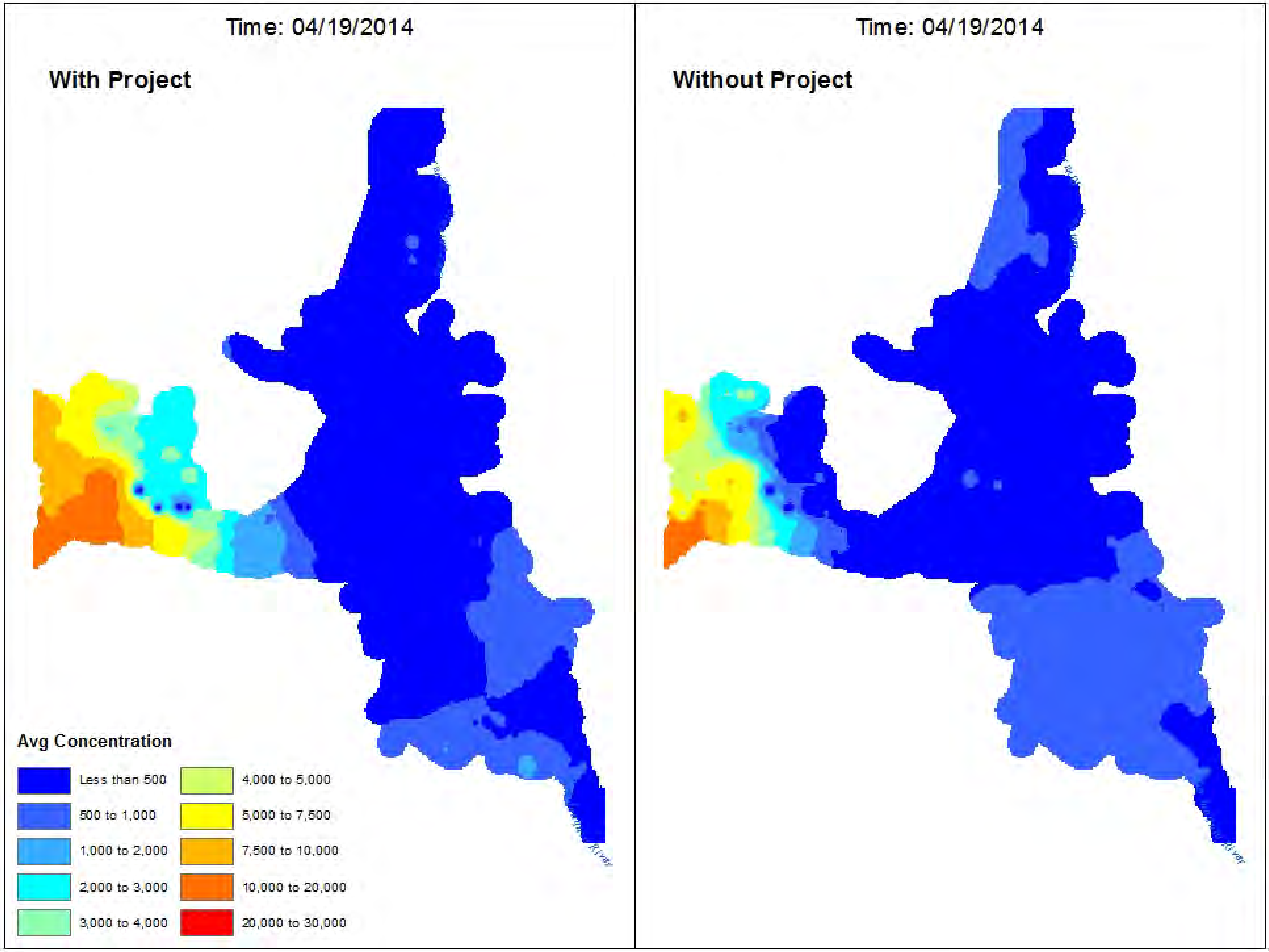

Time: 11/30/2013
With Project
Time: 11/30/2013
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River

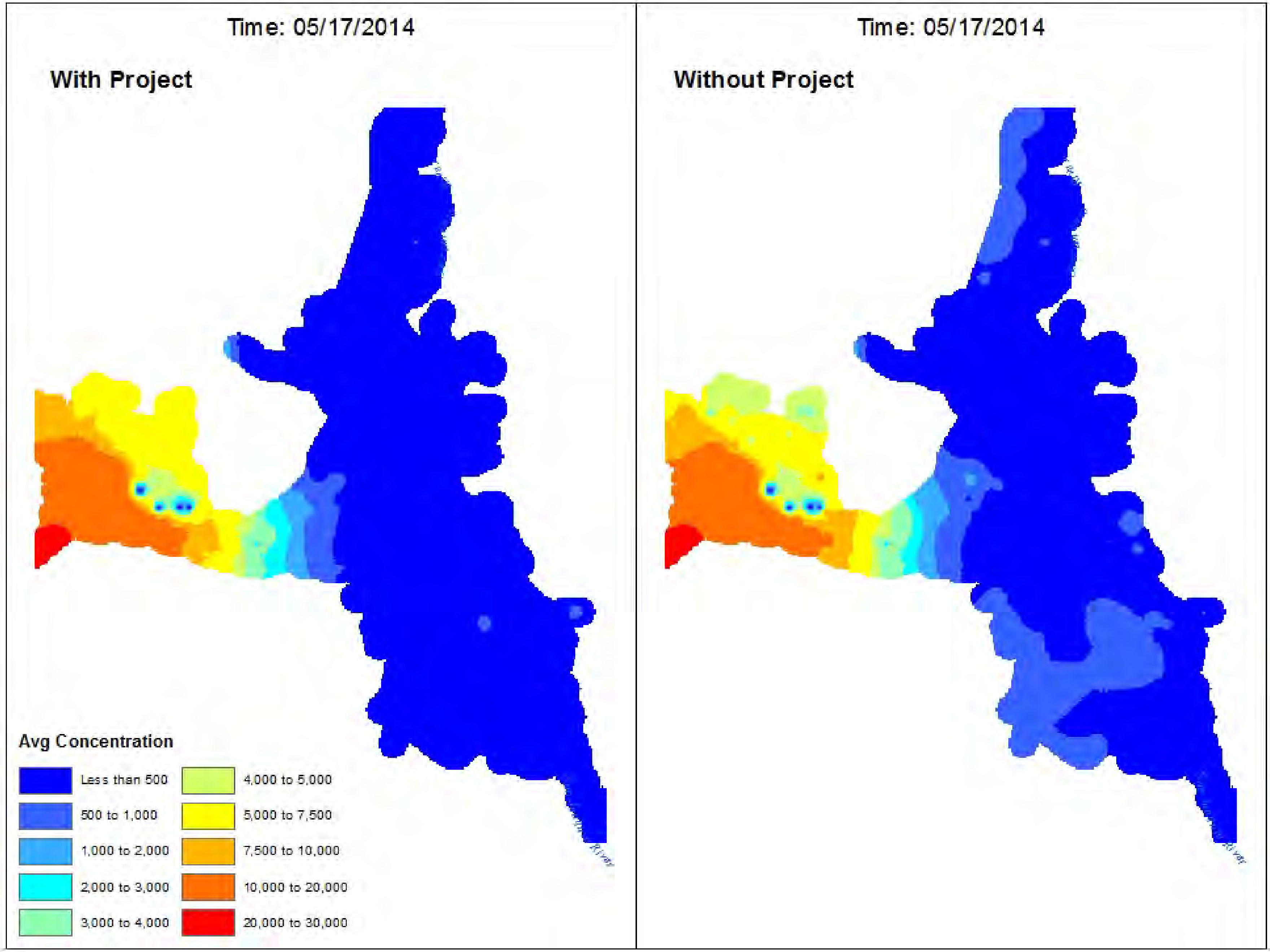

Time: 12/28/2013
With Project
Time: 12/28/2013
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River

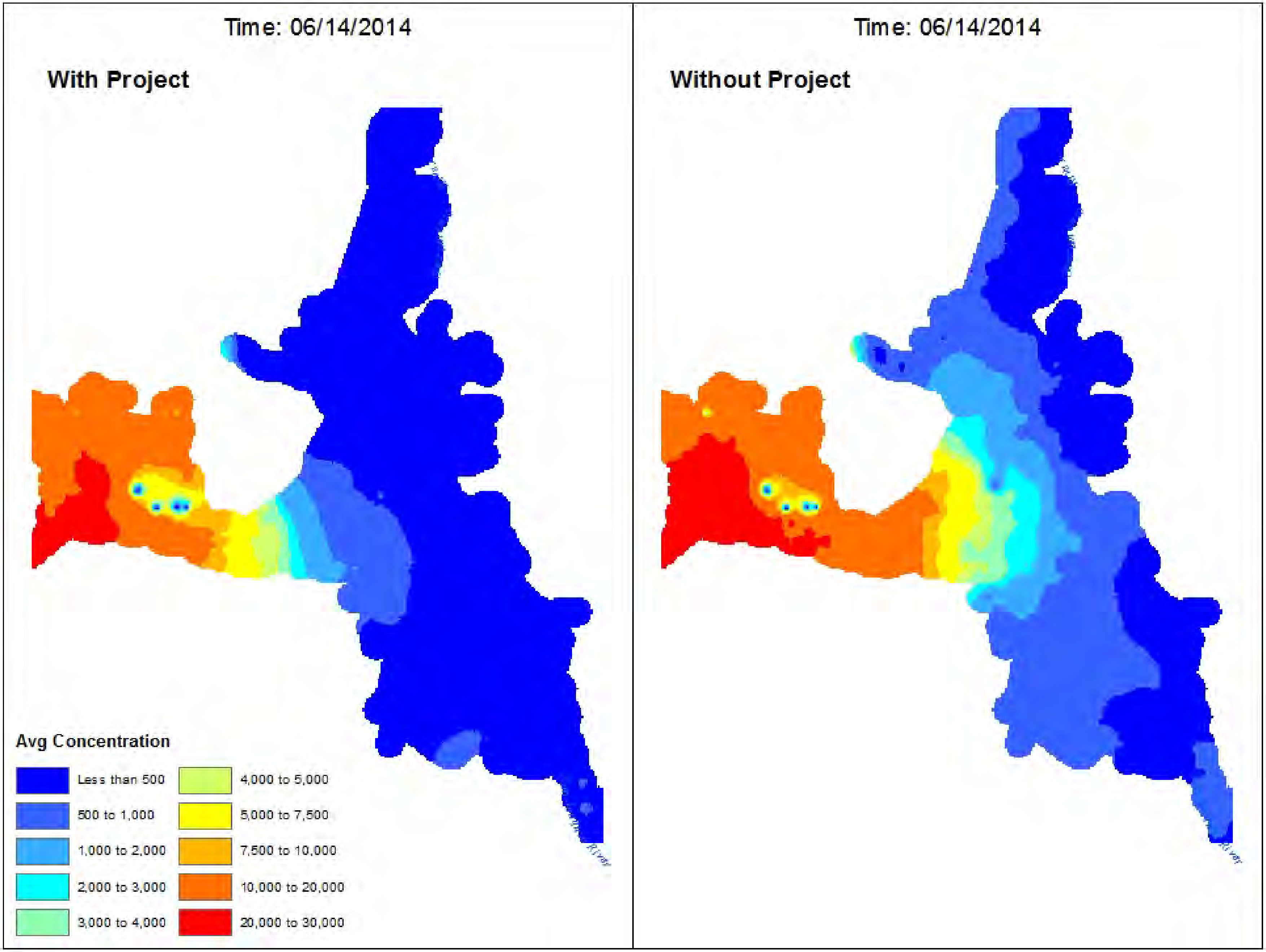

Time: 01/25/2014
With Project
Time: 01/25/2014
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River


Time: 02/22/2014
With Project
Time: 02/22/2014
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000


Time: 03/22/2014
With Project
Time: 03/22/2014
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River


Time: 04/19/2014
With Project
Time: 04/19/2014
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River


Time: 05/17/2014
With Project
Time: 05/17/2014
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River

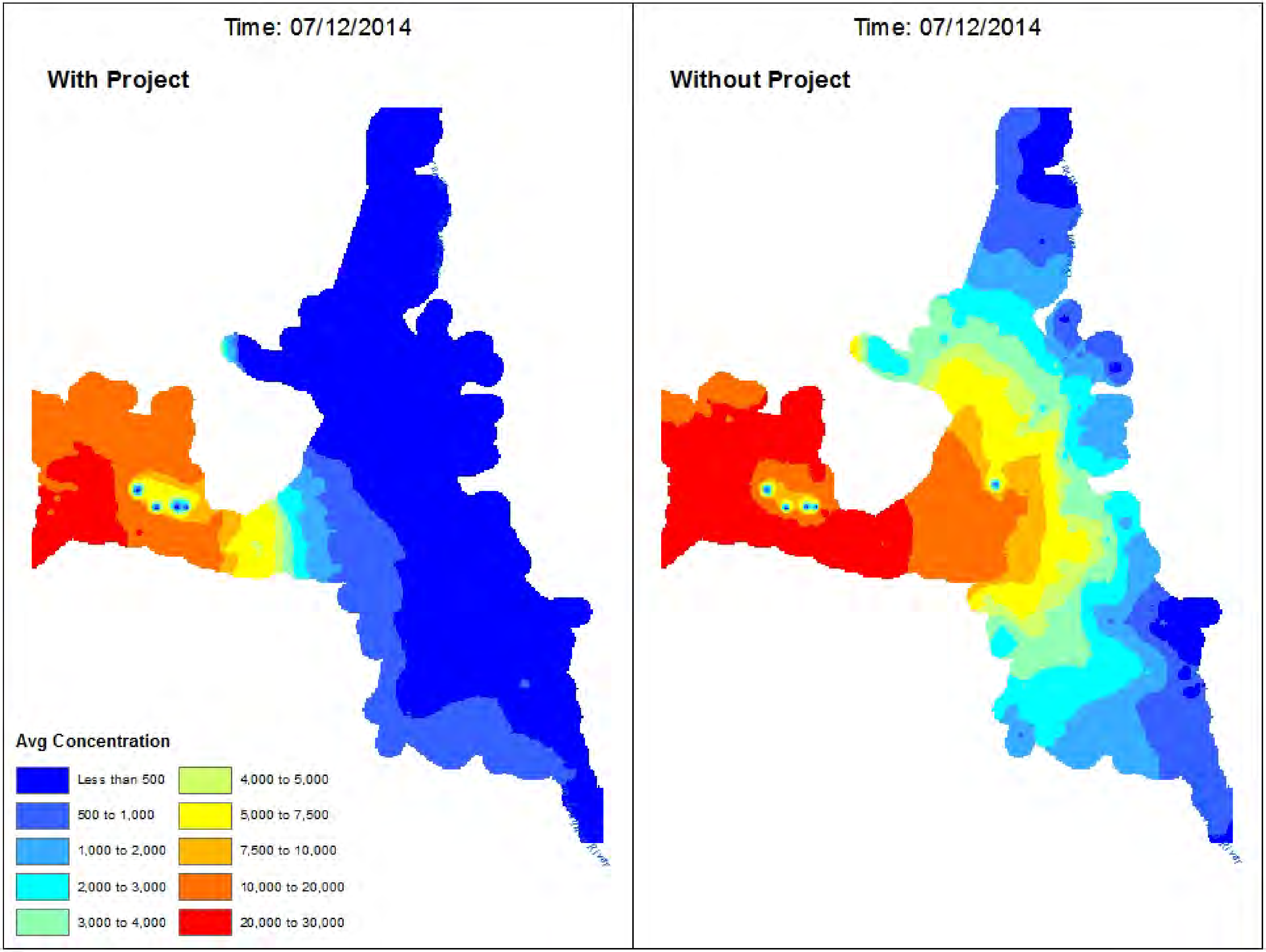


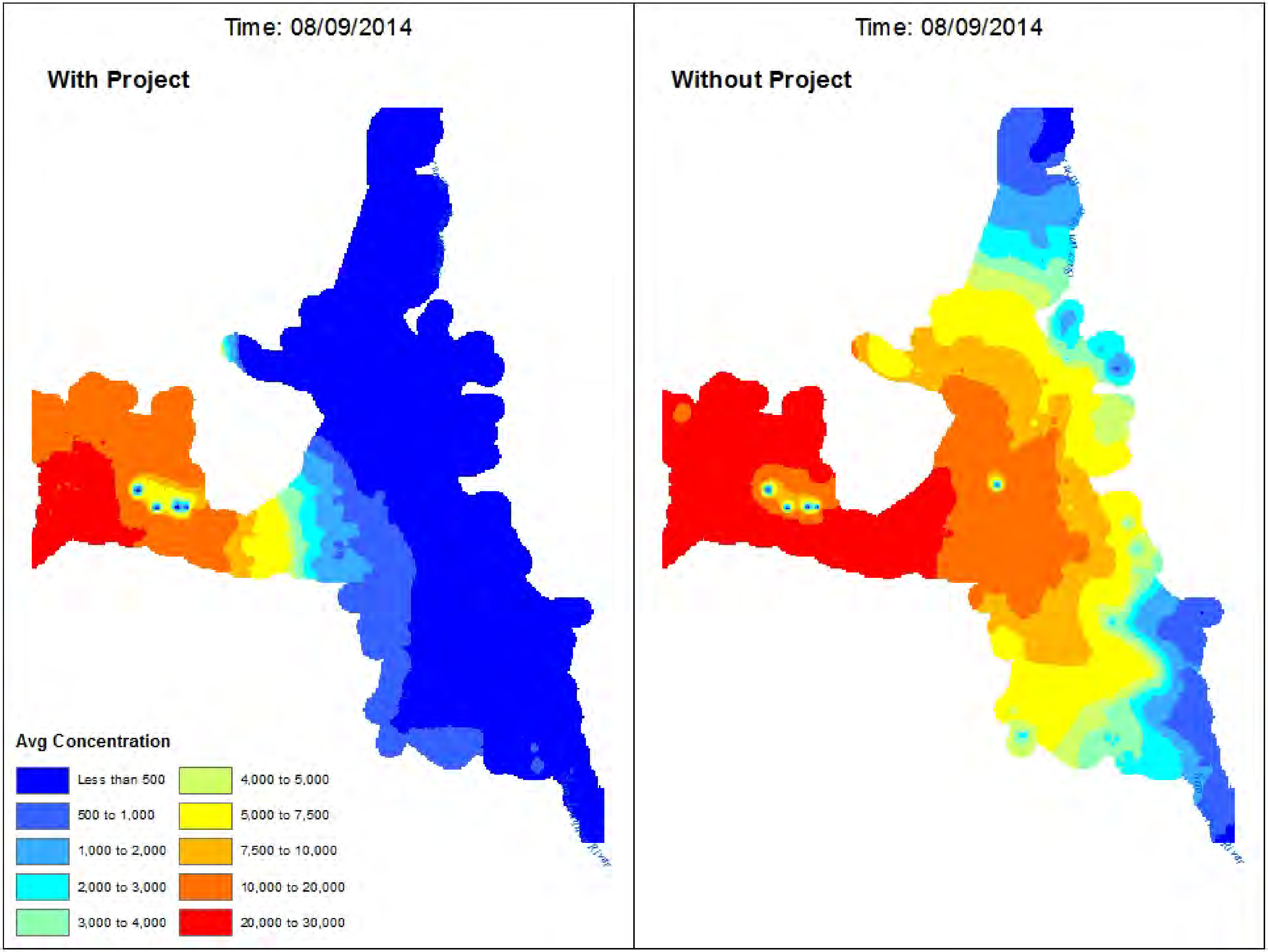
Time: 06/14/2014

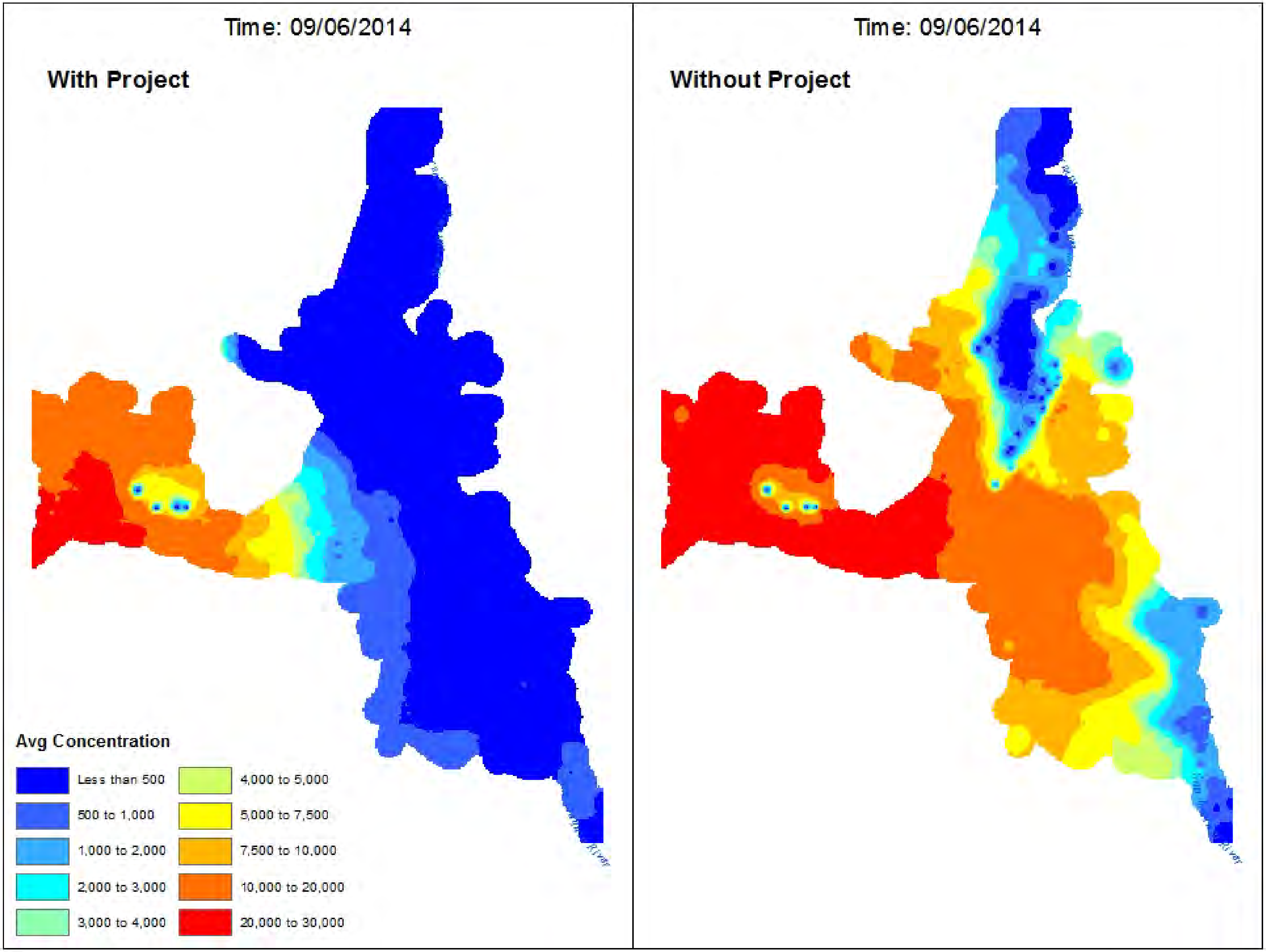
With Project

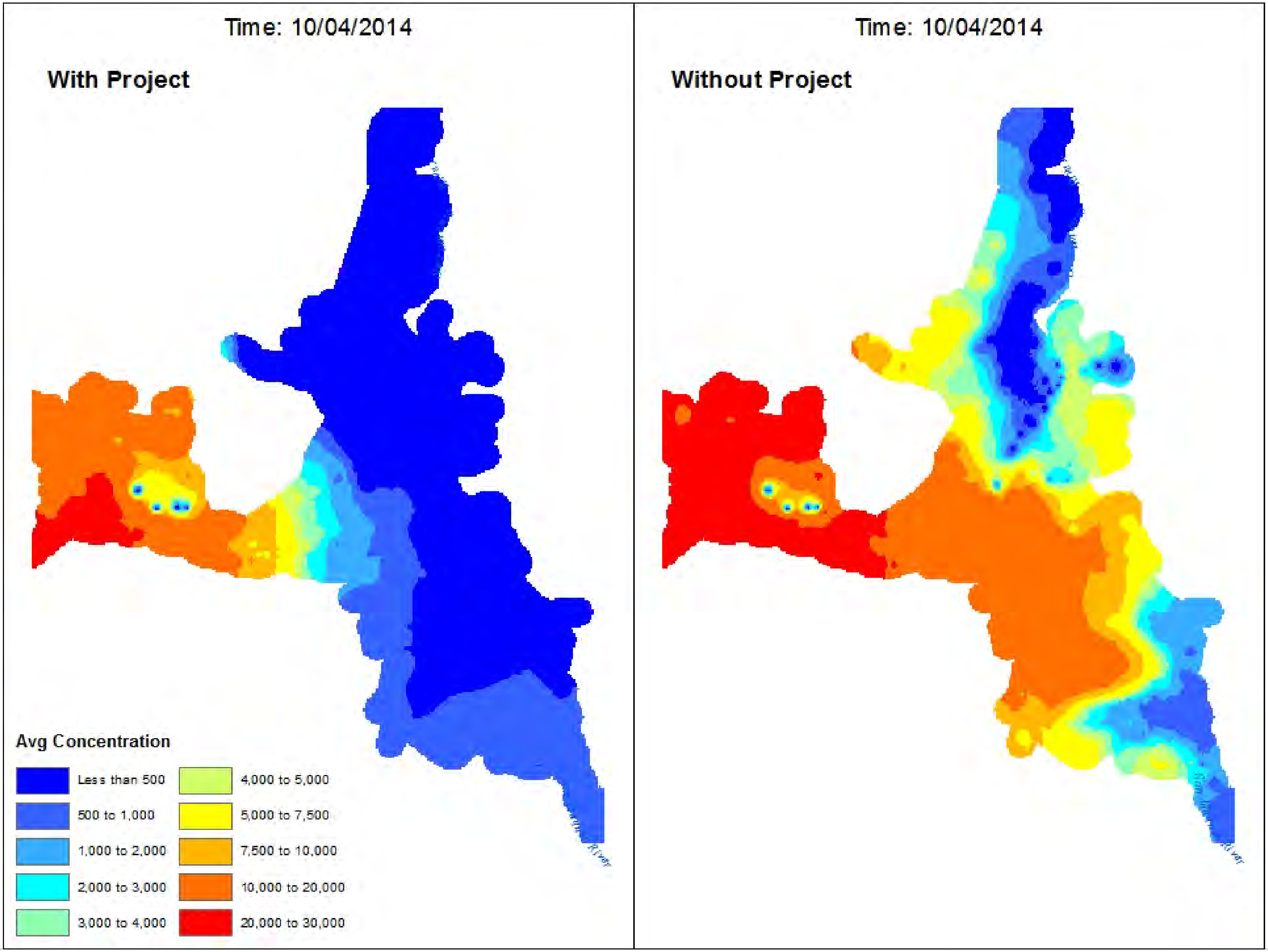
Time: 06/14/2014

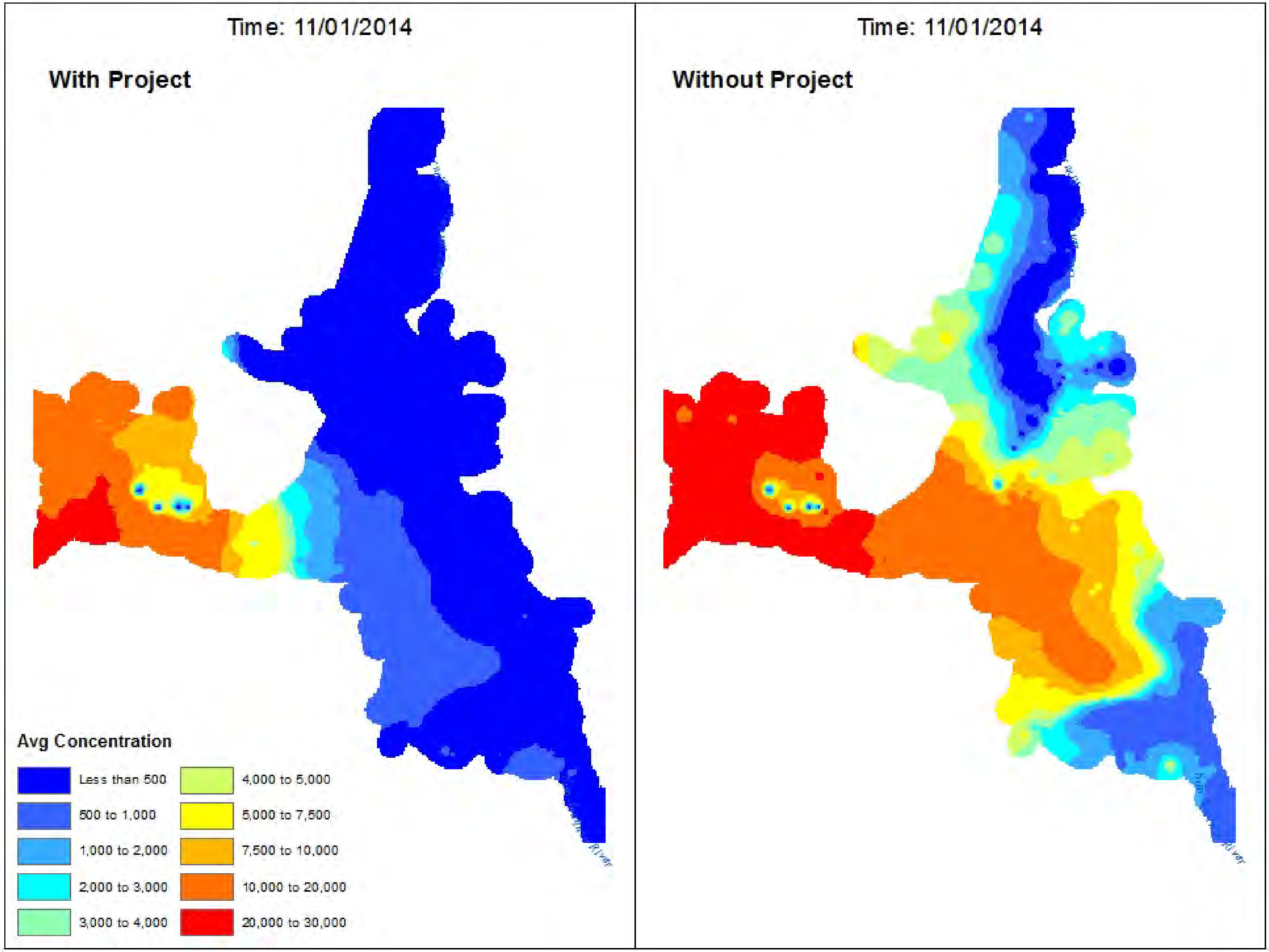
Without Project

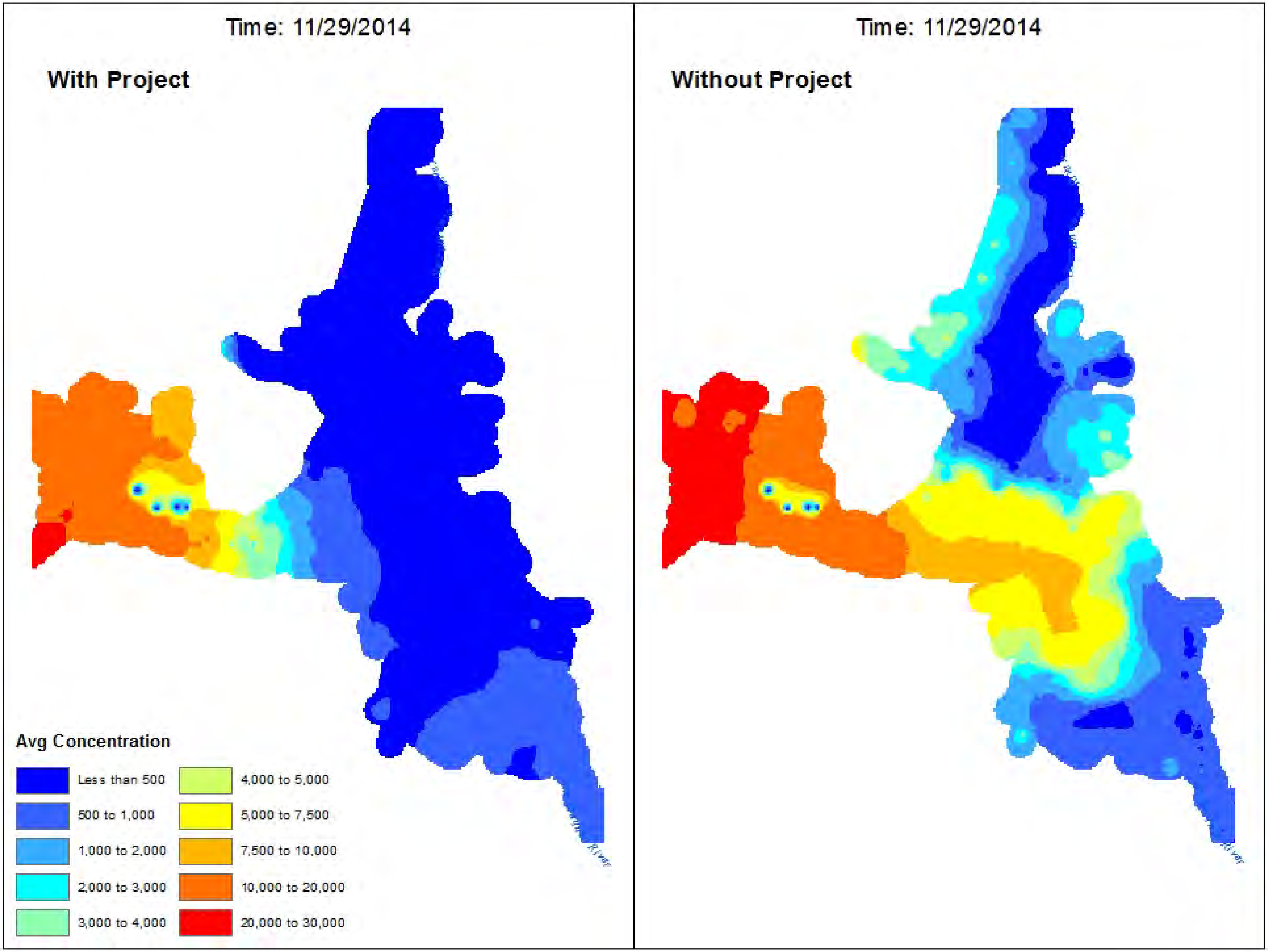

Time: 07/12/2014
With Project
Time: 07/12/2014
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River

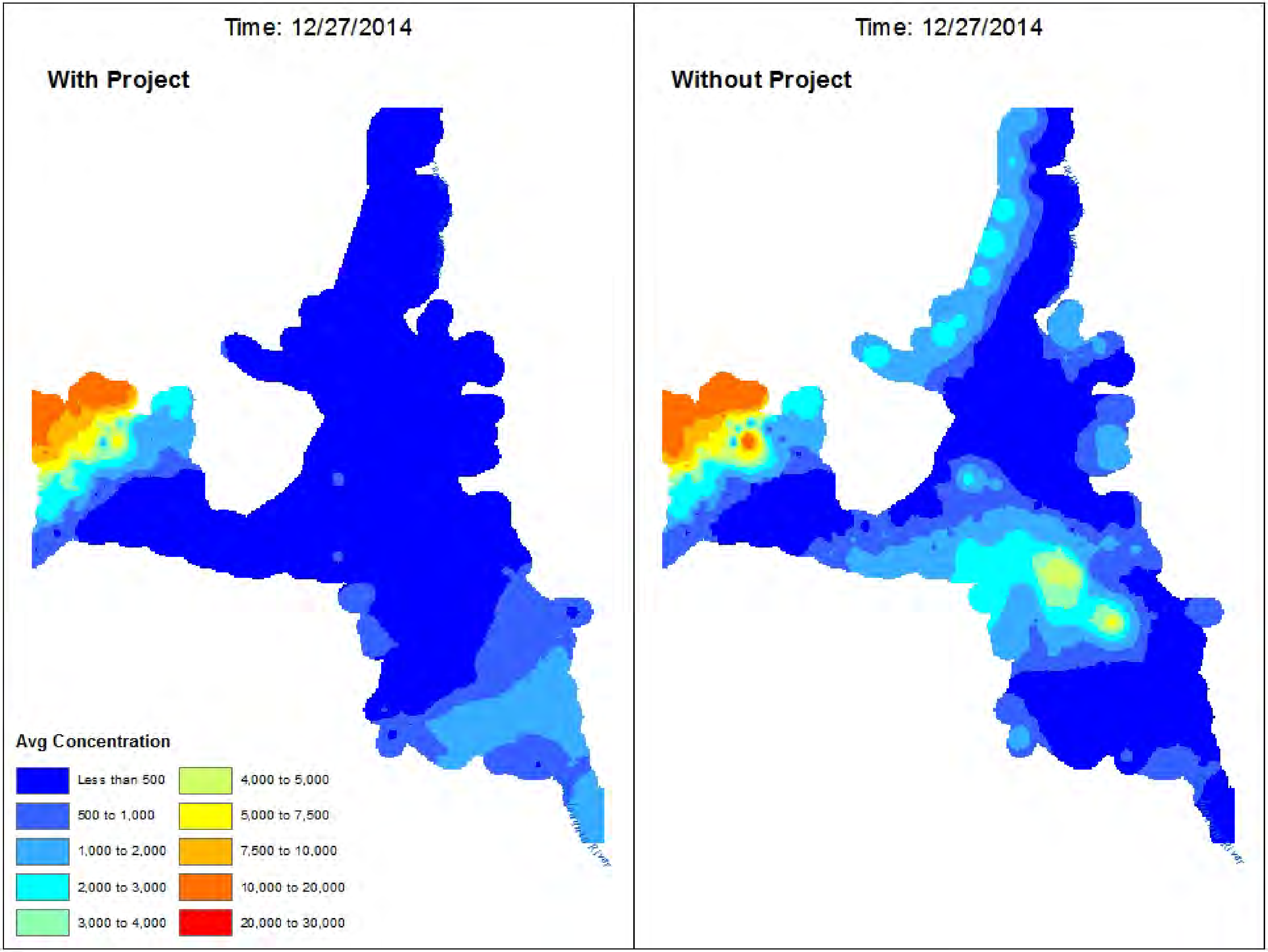

Time: 08/09/2014
With Project
Time: 08/09/2014
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River

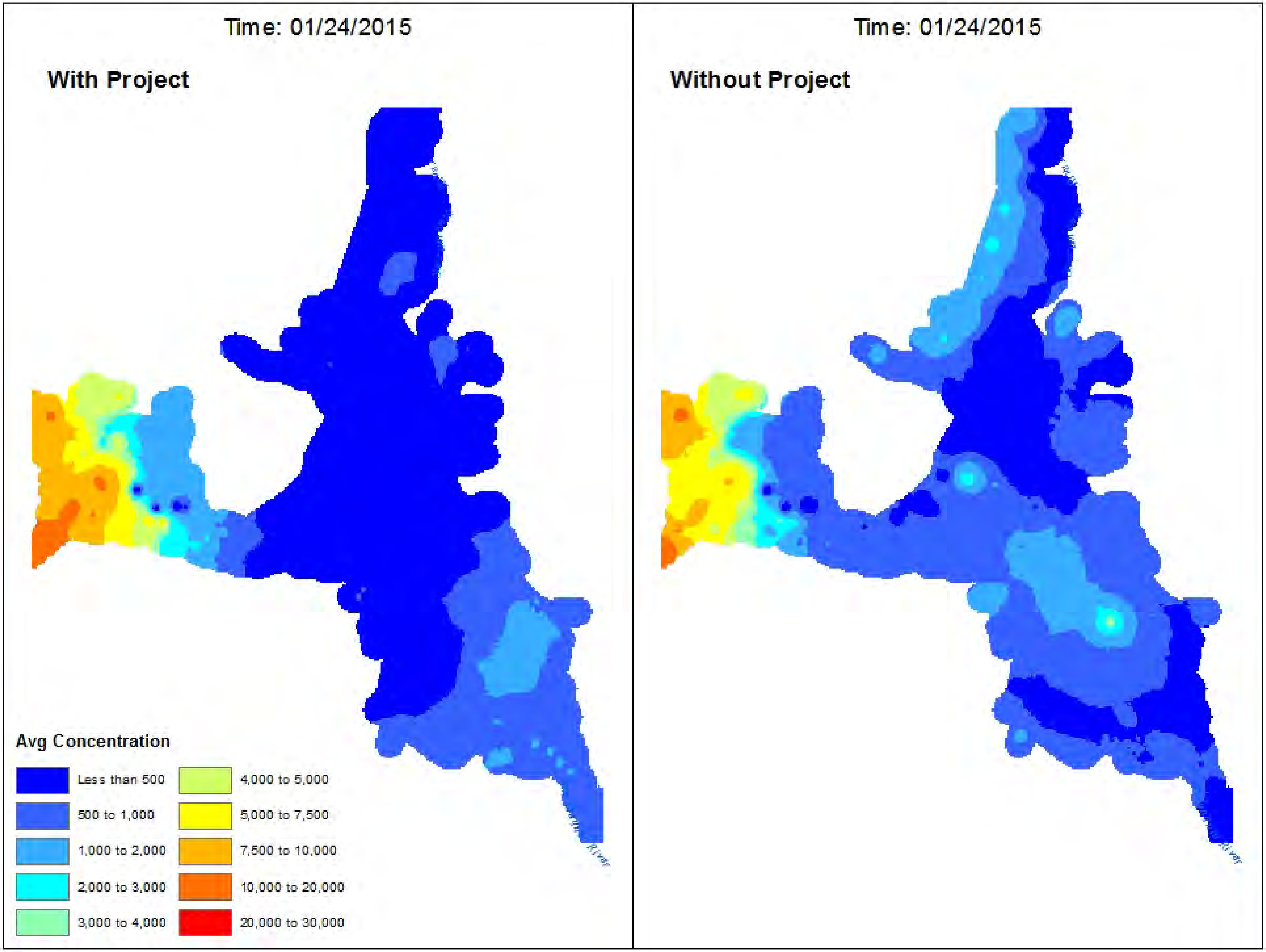

Time: 09/06/2014
With Project
Time: 09/06/2014
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River

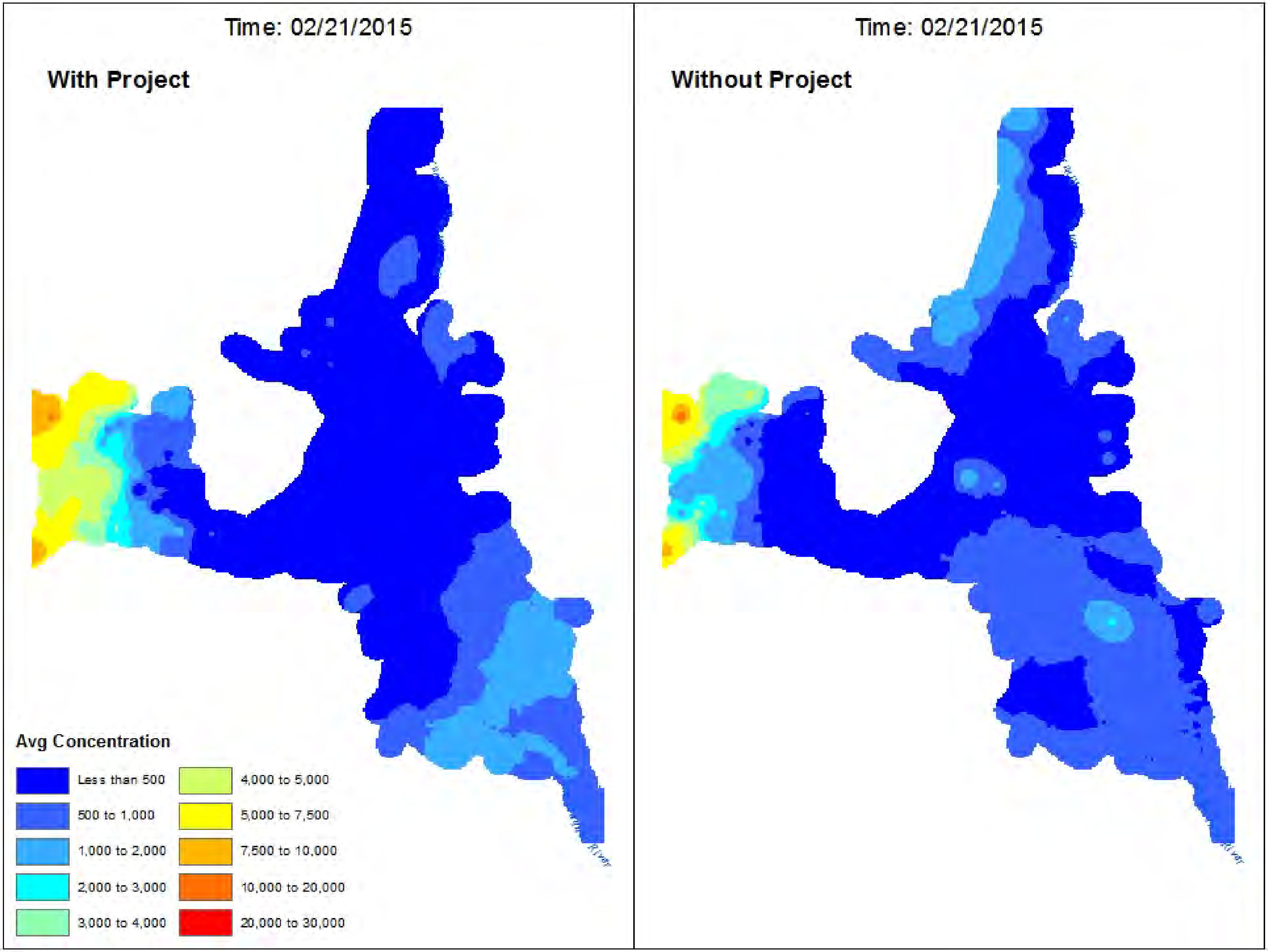

Time: 10/04/2014
With Project
Time: 10/04/2014
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River

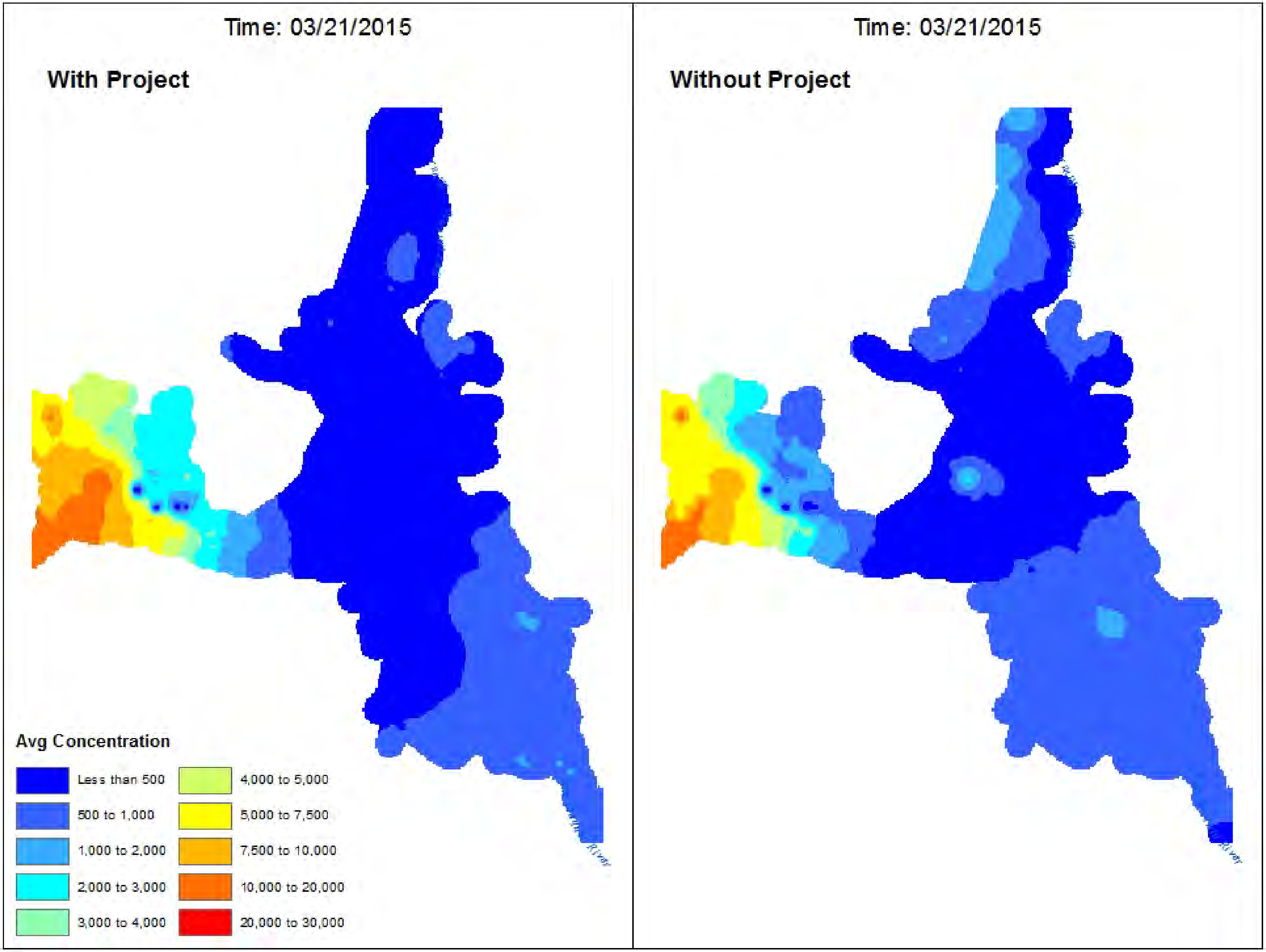

Time: 11/01/2014
With Project
Time: 11/01/2014
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River

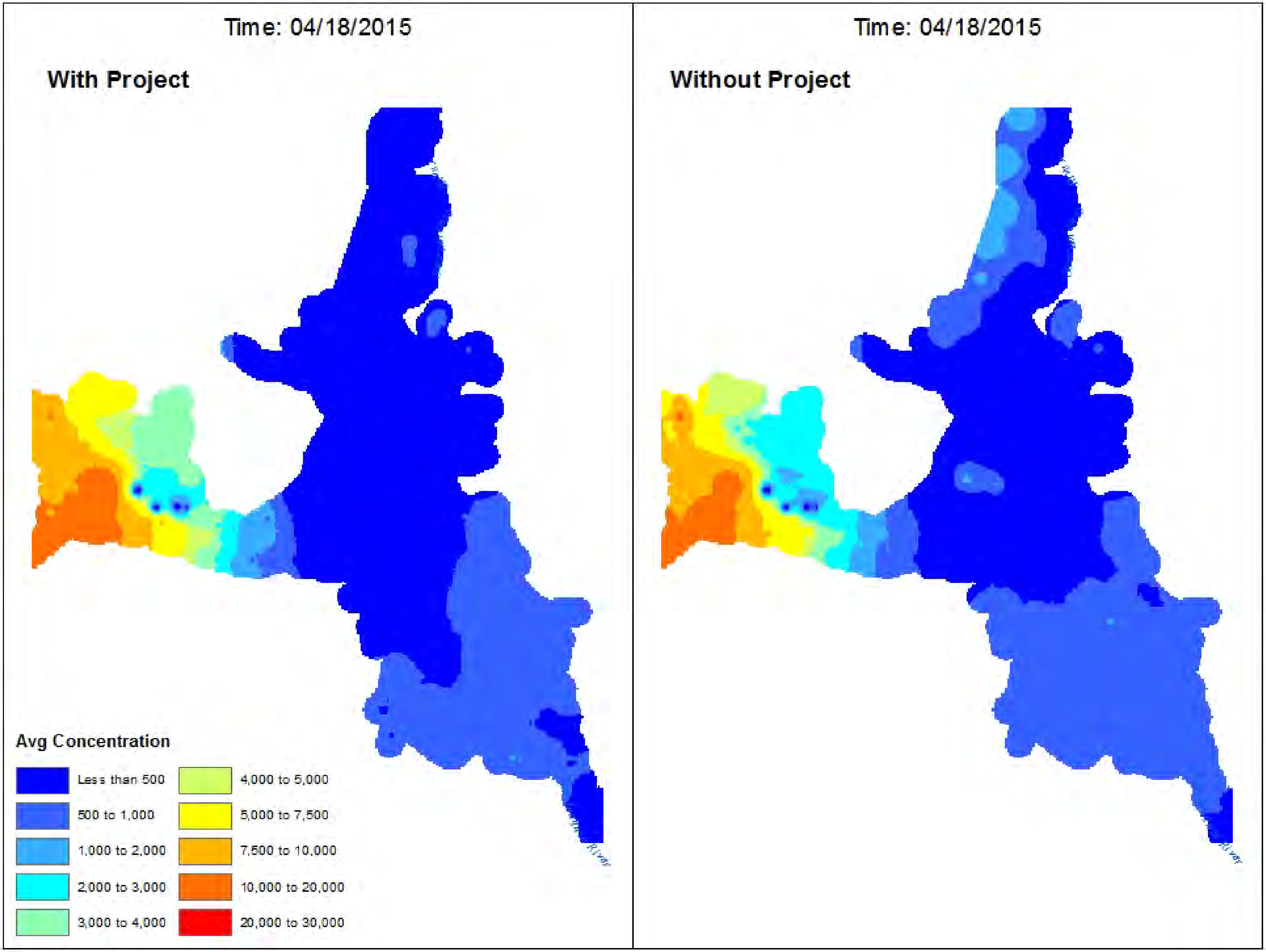

Time: 11/29/2014
With Project
Time: 11/29/2014
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River

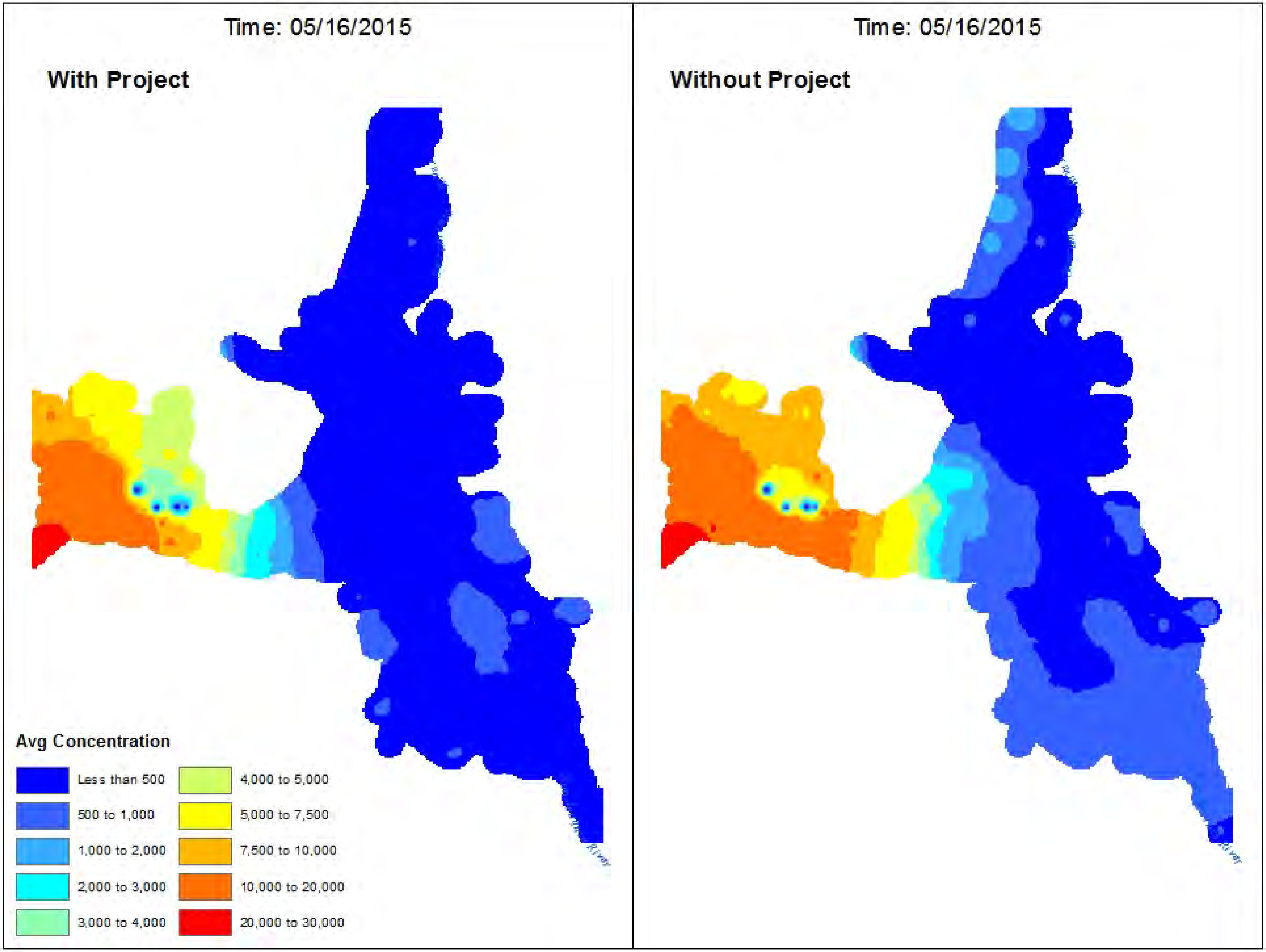

Time: 12/27/2014
With Project
Time: 12/27/2014
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000

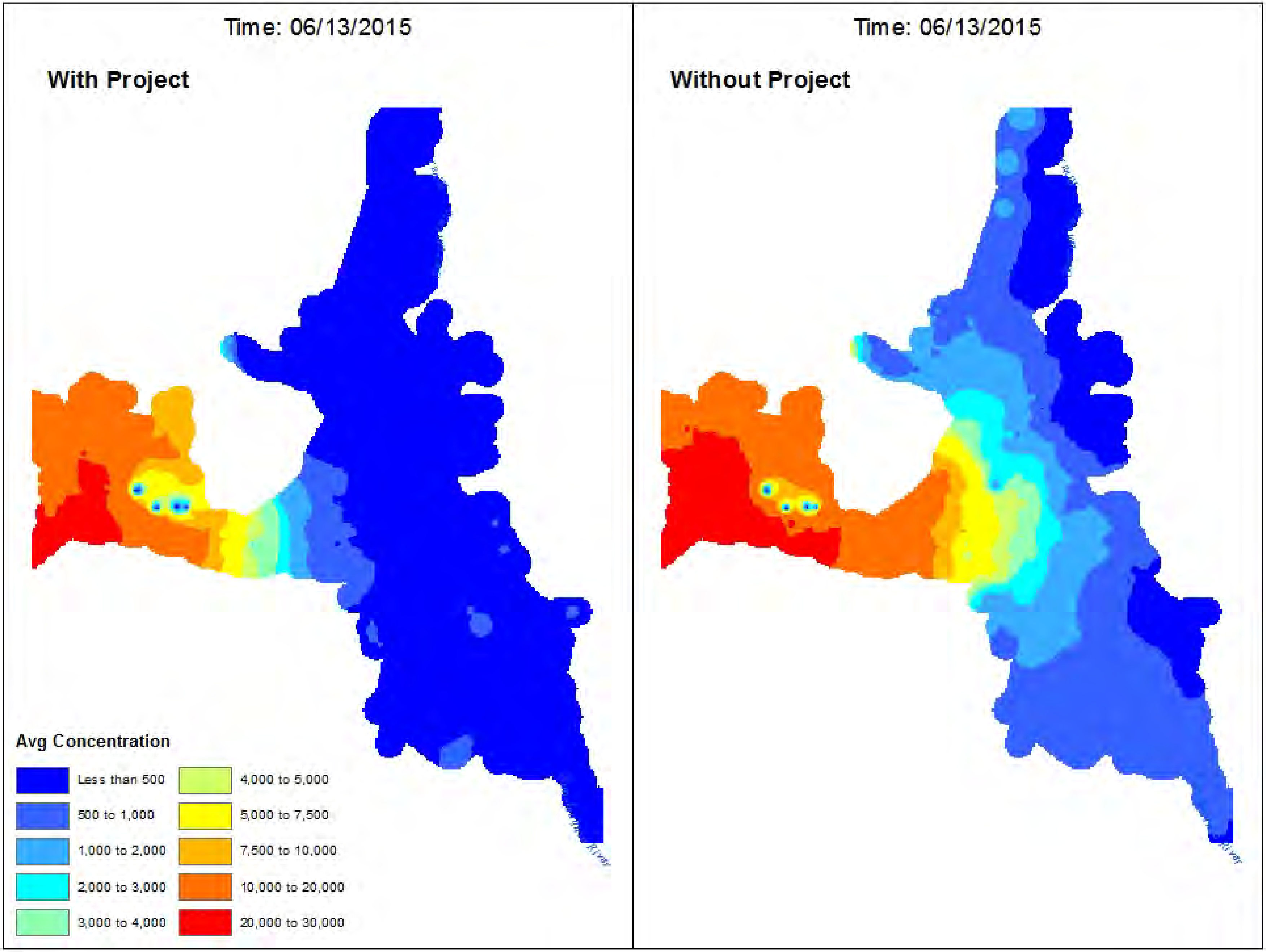

Time: 01/24/2015
With Project
Time: 01/24/2015
Without Project
River
River
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000

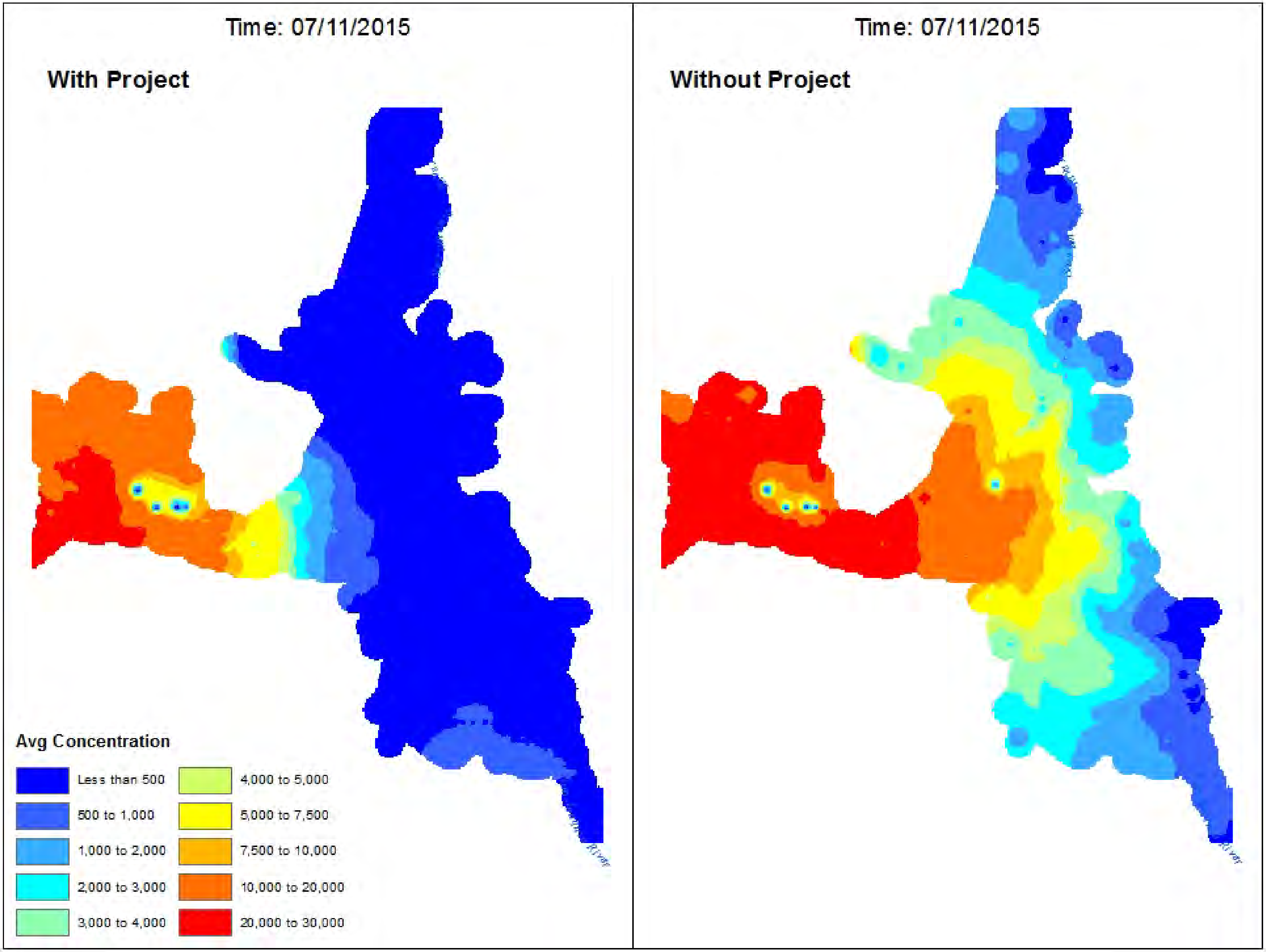

Time: 02/21/2015
With Project
Time: 02/21/2015
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River

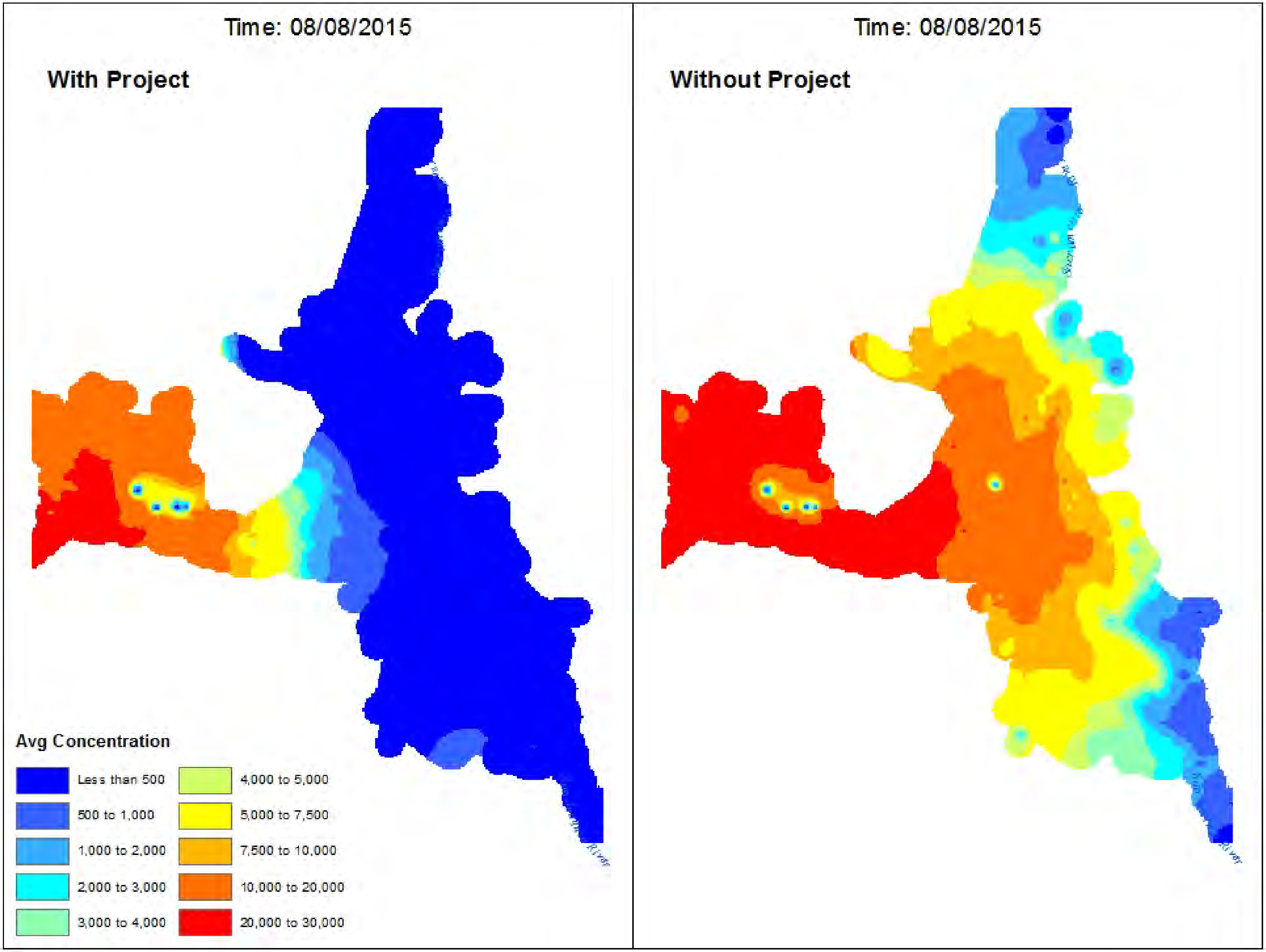

Time: 03/21/2015
With Project
Time: 03/21/2015
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River

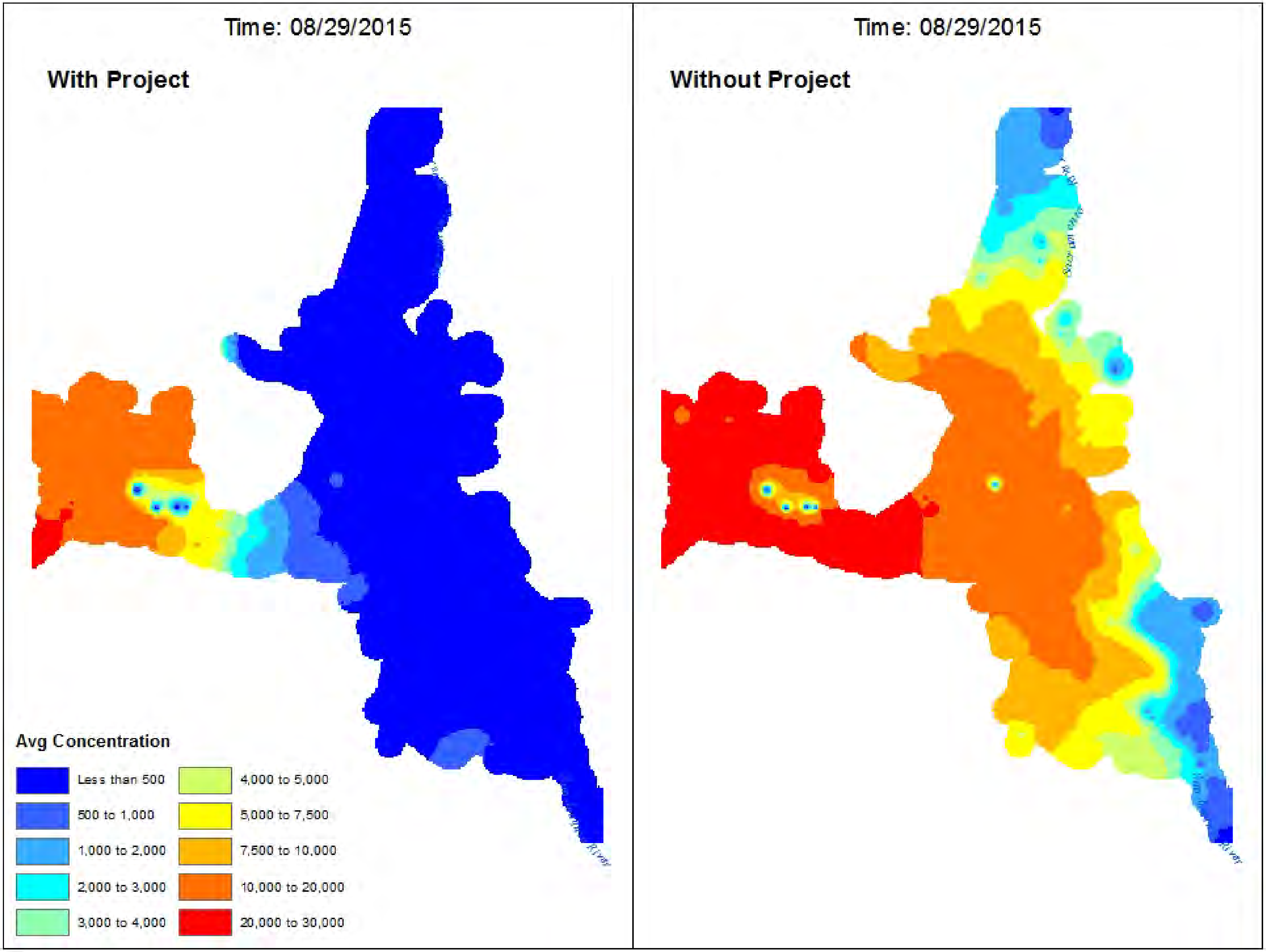

Time: 04/18/2015
With Project
Time: 04/18/2015
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River


Time: 05/16/2015
With Project
Time: 05/16/2015
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River


Time: 06/13/2015
With Project
Time: 06/13/2015
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River


Time: 07/11/2015
With Project
Time: 07/11/2015
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River


Time: 08/08/2015
With Project
Time: 08/08/2015
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River


Time: 08/29/2015
With Project
Time: 08/29/2015
Without Project
Avg Concentration
Less than 500
500 to 1,000
1,000 to 2,000
2,000 to 3,000
3,000 to 4,000
4,000 to 5,000
5,000 to 7,500
7,500 to 10,000
10,000 to 20,000
20,000 to 30,000
River
River

Appendix A: Methodology to Estimate Vernalis Salinity Under Without Project Conditions (from USBR & SDWA 1980) – provided by SWC

Calculate Salt Load Based on Flow (Table VI-7, page 89)

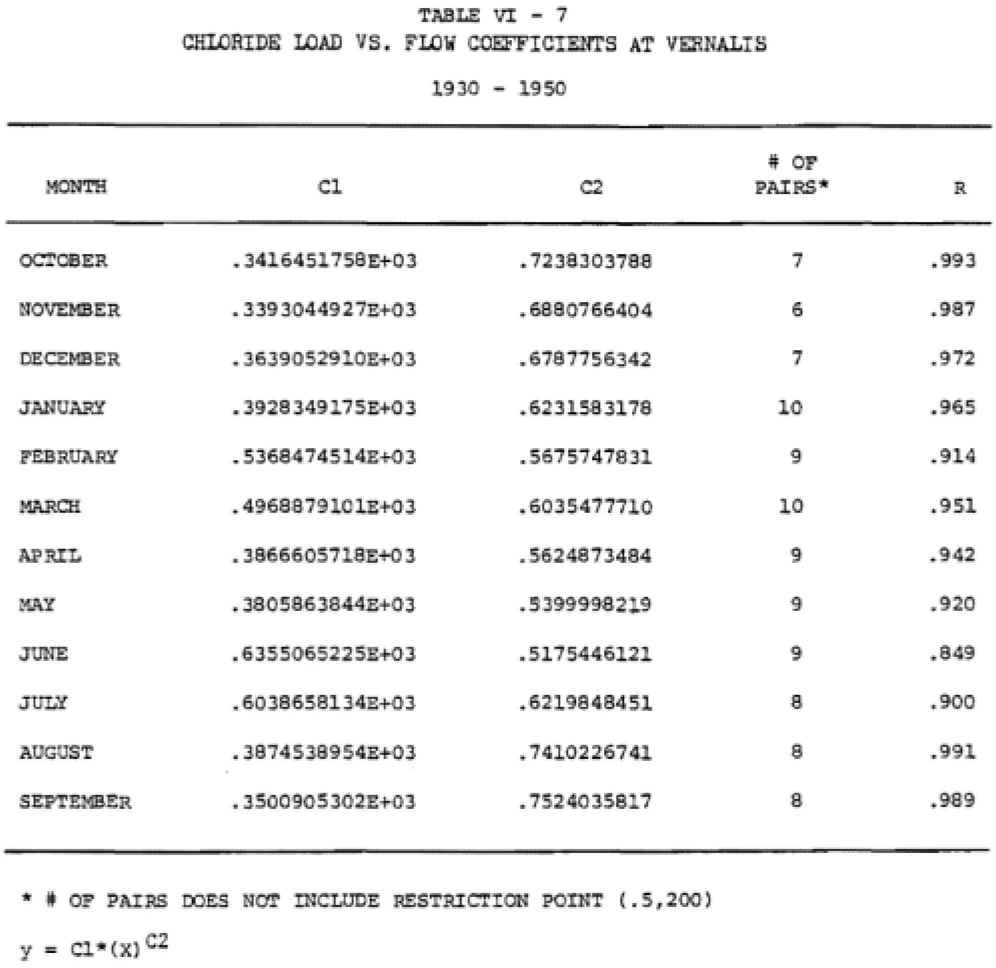


TABLE VI - 7

CHLORIDE LOAD VS. FLOW COEFFICIENTS AT VERNALIS

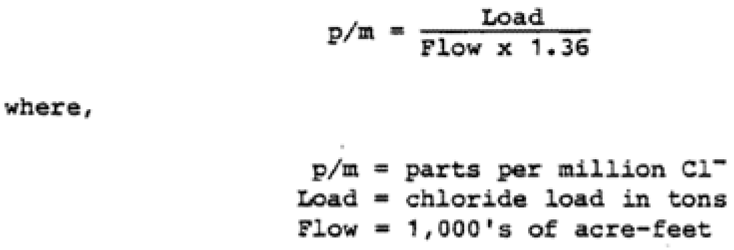
1930 - 1950

MONTH	C1	C2	# OF PAIRS*	R
OCTOBER	.3416451758E+03	.7238303788	7	.993
NOVEMBER	.3393044927E+03	.6880766404	6	.987
DECEMBER	.3639052910E+03	.6787756342	7	.972
JANUARY	.3928349175E+03	.6231583178	10	.965
FEBRUARY	.5368474514E+03	.5675747831	9	.914
MARCH	.4968879101E+03	.6035477710	10	.951
APRIL	.3866605718E+03	.5624873484	9	.942
MAY	.3805863844E+03	.5399998219	9	.920
JUNE	.6355065225E+03	.5175446121	9	.849
JULY	.6038658134E+03	.6219848451	8	.900
AUGUST	.3874538954E+03	.7410226741	8	.991
SEPTEMBER	.3500905302E+03	.7524035817	8	.989

* # OF PAIRS DOES NOT INCLUDE RESTRICTION POINT (.5,200)

$y = C1*(X)^{C2}$

Convert Salt Load to Chloride Concentration (page 110)



$$p/m = \frac{\text{Load}}{\text{Flow} \times 1.36}$$

where,

p/m = parts per million Cl^-
Load = chloride load in tons
Flow = 1,000's of acre-feet

Calculate Specific Conductance EC from Chloride Concentration (page 86)

$$Cl^{-} = 0.15\ EC - 5.0 \tag{2a}$$

$$0 < EC < 500$$

$$Cl^{-} = 0.202\ EC - 31.0 \tag{2b}$$

$$500 < EC < 2000$$

Rearranging the equations to solve for EC yields:

$EC = (Cl- + 5.0) / 0.15 \qquad 0 < EC < 500$

$EC = (Cl- + 31.0) / 0.202\ 500 < EC < 2000$