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October 5, 2016

Rich Satkowski
State Water Resources Control Board, Division of Water Rights
1001 I Street
Sacramento, CA 95814

Dear Mr. Satkowski:

Re: An Independent Peer Review Report for the Delta Science Program on the DWR report "On Estimating Net Delta Outflow (NDO): Approaches to Estimating NDO in the Sacramento-San Joaquin Delta"

The Delta Science Program is pleased to present the enclosed review report entitled, "An Independent Peer Review Report for the Delta Science Program on the DWR report On Estimating Net Delta Outflow (NDO): Approaches to Estimating NDO in the Sacramento-San Joaquin Delta". The transmittal of this report fulfills a request from the State Water Resources Control Board (Water Board) for the Delta Science Program to facilitate a peer review of the Department of Water Resources (DWR) report on appropriate methodologies for determining NDO.

The overall goal of this peer review was to evaluate proposed methodological improvements to the estimation of net Delta outflow to inform the State Water Board's decisions regarding the formulation of regulatory parameters to manage net Delta outflow. The review highlighted the challenges and importance of estimating net Delta outflow, especially during drought conditions. The review included discussion of the report submitted by the DWR, "On Estimating Net Delta Outflow (NDO): Approaches to Estimating NDO in the Sacramento-San Joaquin Delta," other reference material supplied with the Independent Peer Review Report, and the personal knowledge and other available references that the panel felt were relevant. Although simple in concept, measurement of NDO continues to be one of the most complex and difficult metrics to quantify as is described in the DWR Report and the Independent Peer Review Report.

The independent review panel consisted of Dr. William Fleenor (Chair), Dr. Peter Goodwin, Dr. Nancy Monsen (Lead Author), and Ms. Cathy Ruhl. These panel members were selected for their expertise and reputation concerning hydrodynamics, ecohydraulics, transport modeling, and flow monitoring.

The subject report "On Estimating Net Delta Outflow (NDO): Approaches to Estimating NDO in the Sacramento-San Joaquin Delta" can be found on the Delta Science Program web page (http://deltacouncil.ca.gov/events/science-program-review/science-review-report-estimating-net-delta-outflow-ndo-approaches). The Delta Science Program was pleased to assist in the process of evaluating the approaches to estimating NDO in the Delta with an open and transparent scientific peer review.

If there are questions about the independent review panel's report or the review process, please contact Nicole Stern, Environmental Scientist, Delta Science Program, at (916) 322-6545.

Sincerely,

Cliff Dahm

Cliff Dahm, Ph.D.
Lead Scientist, Delta Science Program
Delta Stewardship Council

Enclosure

cc: Diane Riddle, State Water Resources Control Board
Matt Holland, State Water Resources Control Board

An Independent Peer Review Report for the

Delta Science Program

On the DWR report

On Estimating Net Delta Outflow (NDO): Approaches to Estimating NDO in the Sacramento-San Joaquin Delta

Prepared by

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Delta Stewardship Council
Delta Science Program

Executive Summary

The peer review panel (Panel) has read and discussed the report, On Estimating Net Delta Outflow (NDO): Approaches to Estimating NDO in the Sacramento-San Joaquin Delta, produced by the Department of Water Resources (DWR) at the request of the State Water Resources Control Board (State Water Board) referred to herein as the Report. The review included discussion of the Report, other reference material supplied with the Report and the personal knowledge and other available references the Panel felt suitable. Although simple in concept, measurement of NDO continues to be one of the most complex and difficult metrics to quantify as is described in the Report and discussed in this review.

Summary responses to the questions posed to the Panel are as follows:

1. Best available information is a challenging standard to meet since there is a very active science community studying factors that contribute to the estimate of Net Delta Outflow and new knowledge is being developed continuously. Also some of this information has yet to be peer-reviewed or validated with different sets of field data. In responding to the questions, the Panel recognizes that the DWR Report was dated March 2016, with much of the materials developed well prior to publication. Where possible, the Panel has indicated where more recent information is or will shortly be available.

   The 1995 Bay-Delta Plan indicated that DWR was then in the process of developing new channel depletion estimates using Delta Island Consumptive Use (DICU). In the intervening 20 years, DICU has been used in other modeling efforts such as DSM2; and limitations and uncertainties with this approach have been identified. Work has been conducted on multiple paths but it is really only in the past 5 years that the emergence of new technologies show promise in helping close the water mass balance for the Delta. The Panel finds the Report provides comprehensive coverage of the problem, but is fragmented, lacking details, and in some places has not included the latest scientific information available.

2. a. The Report recommends the continued use of the Net Delta Outflow Index (NDOI) as being the most suitable for regulatory purpose use. It does suggest the incorporation of DICU to improve consumptive use estimates and the correction of known water accounting errors but does not list what errors would be corrected. The charge to DWR had not requested a recommendation of what to use as a regulatory metric, but only a recommended method for measuring Net Delta Outflow (NDO). The Report details the difference between NDOI and NDO, but does not advise on the best method to measure NDO.

2. b. The Report references the DICU model as the most mature approach. While DICU has been in development for over 20 years, it is unclear why DWR is reluctant to use DETAW rather than DICU. The Report states “different from DICU, DETAW has been calibrated and validated based on independent estimates of net consumptive use …” (pg. 14, para 1). Challenges still remain in computing estimates of consumptive use;

each method suffers from groundwater/seepage unknowns and unknown lags between diversion and returns.

2. c. The Report assessment of acoustic measurement accuracies has some merit in that tidal asymmetries, complex flow structure, and channel sizes pose serious challenges. However, much of this could be overcome from a more systematic approach to measurement and analysis. Further, recent analysis has demonstrated that direct measurement and current Dayflow estimates have comparable accuracies, with timing differences explained by filling and draining of the Delta (Stephen Monismith pers. comm.).

2. d. The Report clearly demonstrates that DWR has done considerable work in attempting to find better ways to estimate net Delta consumption, however all approaches require more work to quantify accuracy and demonstrate the most appropriate methodology.

3. Considering the uncertainties and accuracy of acoustic flow measurements claimed by DWR in the Report, it is unclear why so much effort has been placed in the multiple control volume analysis. The multiple control volume analysis could possibly provide insight into the robustness of the existing station calibrations and be used to identify where additional focus may be required. The Report is too short on specific details of this method to fully judge its efficacy. However, a more systematic approach to this Control Volume approach should be taken that includes an error analysis. The Report has not fully examined the salinity inversion techniques and work performed to date. Measurement of salinity will likely always be more accurate than flows; and the use of well-calibrated, three-dimensional models with salinity measurements could be more cost efficient than other methods. However, current attempts (*e.g.*, MacWilliams *et al.* 2015) continue to include significant assumption with the integration of DICU or Dayflow. Salinity inversion techniques, or direct near-time simulation of flow and salinity structure hold considerable promise with the rapid developments in sensor technology, particularly with a range of experts drawn together to provide key information and uncertainty estimates.

4. The Report lacks specific technical background in most sections. Daily NDO estimates based on a Dayflow type of accounting will require much better information on diversion, returns and consumptive use along with adjustment for filling and draining associated with short-term sea level variability, wind fetch, and spring-neap tide cycles. The approach that shows most promise of obtaining better estimates is through direct metering of diversions and returns and consumptive use estimates from the emerging remote sensing techniques combined with higher resolution meteorology within the Delta. Salinity will always be more easily and accurately measured than flow rates. Coupled with well-calibrated three-dimensional models, flow can possibly be more accurately estimated from salinity inversion techniques. However, currently the models also suffer from lack of accurate in-Delta water use.

5. One recommendation of the Panel is to consider a focused synthesis activity that harnesses the considerable expertise and activities within DWR, other agencies and universities. This activity – rather like the Pelagic Organism Decline Study of IEP would link concerted field monitoring campaigns with a range of models to systematically compare the methodologies investigated here as well as others. This would result in a comprehensive quantification of measurement error and uncertainties and a standard methodology supported by the scientific community and refined as monitoring resolution and technologies improve. This could be a standing Task Force if necessary.

Foreword

The purpose of this peer review is to evaluate proposed methodological improvements to the estimation of net Delta outflow to inform the State Water Resources Control Board's (State Water Board) decisions regarding the formulation of regulatory parameters to manage net Delta outflow. The Panel understands that the Report and its technical evaluation will inform the scientific basis for updates to the Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (Bay-Delta Plan). The Report, "On Estimating Net Delta Outflow (NDO): Approaches to Estimating NDO in the Sacramento-San Joaquin Delta" was prepared by the Department of Water Resources and provided to the Panel by the Delta Stewardship Council/Delta Science Program. The Panel has reviewed the Report and supporting information (both supplied and others identified by the panelists as pertinent) necessary to evaluate its contents in light of the charge questions posed below.

Charge to the Panel
The Panel is charged with reviewing and assessing the provided written materials in order to identify the best available science regarding net Delta outflow to inform the State Water Board's decisions on Bay-Delta Plan requirements related to Delta outflow. The Panel will evaluate and synthesize the best available scientific information and prepare a report that addresses the following questions:

1. How well does the 2016 report provided by DWR, "On Estimating Net Delta Outflow (NDO): Approaches to estimating NDO in the Sacramento-San Joaquin Delta" (the DWR report) respond to the State Water Board's request? That is, are the methods for estimating consumptive use and channel depletions and the underlying data and methods the best available?

2. Does the DWR report provide a firm technical basis for its key conclusions and recommendations? Specifically, the following conclusions and recommendations from pages 1-2 of the DWR report:

    a. A water balance approach similar to the Net Delta Outflow Index (NDOI) remains the most suitable tool to define net Delta outflow for regulatory purposes, but should be updated to incorporate improvements to consumptive use estimates and correct a few known water accounting errors.

    b. The Delta Island Consumptive Use model (DICU) is the most mature consumptive use estimate, and should be used to calculate NDOI until an improved daily model, such as DETAW, is sufficiently validated and officially released.

    c. Direct measurement of net Delta outflow using the United States Geological Survey (USGS) acoustic Doppler current profiler (ADCP) stations at Rio Vista, Jersey Point, Dutch Slough, and Threemile Slough is inaccurate, and should not be used.

    d. More studies are needed.

The charge given to DWR by the State Water Board was simply stated:

> "we request that DWR provide its best available estimates of Delta consumptive uses and channel depletions, the data and methods underlying those estimates, and a recommended method for estimating net Delta outflow in real time on a daily time scale".

The Panel will respond to the charge questions understanding the specific request of the State Water Board to DWR and in light of the background provided to the Panel and detailed in the Panel Analysis section.

Background

The State Water Board is currently undertaking a phased process to develop and implement updates to the Bay-Delta Plan and flow objectives for priority tributaries to the Delta to protect beneficial uses in the Bay-Delta watershed. The Bay-Delta Plan identifies beneficial uses of Bay-Delta waters, water quality objectives for the reasonable protection of those beneficial uses, a program of implementation for achieving the water quality objectives and an associated surveillance and monitoring program. Phase 1 of the review of the Bay-Delta Plan is focused on southern Delta water quality and San Joaquin River flows. Phase 2 (Comprehensive Review) is focused on other changes that may be needed to the remainder of the Bay-Delta Plan to protect beneficial uses, including fish and wildlife beneficial uses. The parameters affecting fish and wildlife beneficial uses include: (1) Delta outflows (net Delta outflow), (2) export constraints, (3) Delta Cross Channel Gate closure requirements, (4) Suisun Marsh requirements; (5) Old and Middle River reverse flows; (6) floodplain habitat flows; (7) changes to the monitoring and special studies program, and (8) other potential changes to the program of implementation. Phase 3 involves changes to water rights and other measures to implement changes to the Bay-Delta Plan from Phases 1 and 2. Phase 4 involves developing and implementing flow objectives for priority Delta tributaries outside of the Bay-Delta Plan updates.

Net Delta outflow is strongly influenced by depletions and accretions within the Delta. When the existing Delta outflow objectives were first adopted in the 1995 Bay-Delta Plan, the best available estimates of gross channel depletions in the Sacramento-San Joaquin Delta were those developed for the Dayflow program, so these were used in the definition of NDOI (1995 Bay-Delta Plan at page 25). The 1995 Bay-Delta Plan indicated that DWR was in the process of developing new channel depletion estimates that would be used in lieu of Dayflow once available (see footnote 2 on page 25 of the 1995 Bay-Delta Plan). State Water Board Decision 1641 (as revised March 15, 2000), which assigned responsibility for implementing the Delta outflow objectives and other Bay-Delta Plan objectives, reiterated this statement (page 190, footnote 2). The 2006 Bay-Delta Plan continues to require that Dayflow channel depletion estimates be used if new estimates were not available (2006 Bay-Delta Plan, figure 4, page 20, footnote 2). In the past twenty years, new depletion estimates have not been incorporated into the NDOI calculation nor have other potential needed improvements to the NDOI calculation been made.

The current drought, as well as numerous technical reports and publications, have demonstrated the need to better estimate Delta outflows, including associated depletions and accretions in the Delta, for multiple critical purposes including water supply availability, expected water quality conditions, and protection of beneficial uses. Consequently, in September 2015, the State Water Board staff requested that DWR provide its best available estimates of Delta consumptive uses and channel depletions, the data and methods underlying those estimates, and a recommended method for estimating net Delta outflow in real time on a daily time scale. DWR provided the Report on April 7, 2016.

The State Water Board has requested the assistance of the Delta Science Program to obtain a technical peer review of the Report provided by DWR in response to this request and to provide further guidance on an appropriate methodology for determining net Delta outflow as a regulatory parameter in the Bay-Delta Plan.

Regulatory Context

The State Water Resources Control Board and the nine Regional Water Quality Control Boards (Water Boards) have broad responsibilities to protect surface and ground water quality and balance competing demands on California water resources through programs that allocate water rights, adjudicate water right disputes, develop statewide and regional water quality control plans and implement and enforce those plans. The State Water Board allocates water rights through an administrative system that is intended to maximize the beneficial uses of water while protecting the public trust, serving the public interest, and preventing the waste and unreasonable use or method of diversion of water. The State Water Board protects water quality by establishing water quality control plans, implementing those plans and enforcing that implementation. Water Quality Control Plans identify existing and potential beneficial uses of waters of the state and establish water quality objectives and implementation measures to reasonably protect the identified beneficial uses along with surveillance and monitoring requirements. While most water quality control planning is done by the Regional Water Quality Control Boards, the State Water Board has authority to adopt statewide Water Quality Control Plans and adopts the Bay-Delta Plan because of the overlapping water quality and water rights issues of statewide significance in the Bay-Delta.

The Bay-Delta Plan includes beneficial uses that fall into three broad categories including: fish and wildlife, agricultural, and municipal and industrial uses. The current Bay-Delta Plan includes water quality objectives to protect the three categories of beneficial uses including: inflows from the Sacramento and San Joaquin Rivers; Delta outflows; water project operations; dissolved oxygen; native salmon protection; and various salinity objectives for the protection of fish and wildlife, agriculture, and municipal and industrial uses. The program of implementation identifies actions needed to protect beneficial uses and implement the water quality objectives, including actions the State Water Board will take, actions that the State Water Board will take with other entities, and actions that other entities should take, including non-flow and water quality actions.

The Bay-Delta Plan like other Water Quality Control Plans is not self-implementing and requires additional actions to be implemented. The primary mechanism for implementing the Bay-Delta Plan in the past has been through the State Water Board's water rights authorities. The water quality control planning process and water rights implementation processes are separate processes governed by separate statutory and regulatory requirements. The water quality control planning process is a quasi-legislative planning process, whereas the water rights process is a more formal evidentiary quasi-judicial process.

Pursuant to state and federal law, the State Water Board is required to regularly review the Bay-Delta Plan to determine what, if any, changes should be made to the Bay-Delta Plan to protect beneficial uses. The State Water Board conducted a review of the current 2006 Bay-Delta Plan in 2009. As a result of several species declines in the Bay-Delta that may be associated with Bay-Delta Plan requirements the State Water Board determined that Delta outflows and other requirements for the protection of fish and wildlife beneficial uses should be considered for potential amendment to ensure the protection of fish and wildlife beneficial uses. The State Water Board started the process of updating the Bay-Delta Plan with Phase 1 in 2009 and Phase 2 in 2012. The update process is being conducted in compliance with applicable statutory and regulatory requirements, including the California Environmental Quality Act (CEQA). The Water Quality Control Planning process is a Certified Regulatory Process pursuant to CEQA. Accordingly, the State Water Board is exempt from preparing an Environmental Impact Report (EIR) for its review. Instead, the State Water Board is preparing a Substitute Environmental Documentation (SED) that is functionally equivalent to a programmatic EIR. In addition to the evaluation of environmental impacts, the SED will also evaluate economic effects and other public interest considerations at a programmatic level. All of this information will be used along with public comments from the public to inform the State Water Board's decisions regarding changes to the Bay-Delta Plan. Prior to implementation through water rights and other measures, additional project specific environmental documentation will be prepared as necessary and other statutory and regulatory requirements will be met.

General Comment on how NDO and NDOI will be used

In the charge to the Panel, the State Water Board stated, "The current drought, as well as numerous technical reports and publications, have demonstrated the need to better estimate Delta outflows, including associated depletions and accretions in the Delta, for multiple critical purposes including water supply availability, expected water quality conditions, and protection of beneficial uses." From the statement, the Panel infers that there were instances in the recent past where the calculated "Delta Outflow" was debated in the context of compliance.

For example, in winter 2014, in the middle of the most recent severe drought, the flow and water quality objectives in State Board D-1641 (SB D-1641) were relaxed for Delta Outflows so that outflows could be maintained between 3,000-4,500 cfs rather than the regulated (dry conditions) 14-day running average Delta Outflow of 4,000 cfs, if exports were maintained less than 1,500 cfs. One of the primary justifications for reducing this "Delta Outflow" requirement was that conserving cold water storage in the major reservoirs became a high priority for salmon spawning temperature requirements below the major dams (State Water Resources Control Board 2014). One major technical problem with reducing the required "Delta Outflow" to this low level was that the errors associated with calculating "Delta Outflow" are in the same range. As a result, the Panel anticipates that there was debate about whether actual flow releases complied with these relaxed regulations.

The question of which "Delta Outflow" calculation is the "best available estimate" unfortunately needs to be answered in the context of a second question: how is the State Water Board intending to apply "Delta Outflow?" As this Panel review will discuss extensively, each "Delta

Outflow" approach has strengths and weaknesses. If "Delta Outflow" is being used as a guideline for long-range planning using a watershed model such as CALSIM II, the specified Delta Outflow for the optimization routine should incorporate either a DICU or DETAW approach to estimate in-Delta consumption because "Delta Outflow" will be a fixed constraint for the optimization program. On the other hand, if the purpose of specifying "Delta Outflow" is for determining compliance during extreme drought conditions, a real-time monitoring technique that accounts for upstream water transport due to tides and meteorological conditions at the western boundary of the Delta, based on either data from real-time observed flow stations or inferred "Delta Outflow" based on observed salinity distributions may be better suited for the question facing the State Water Board.

Panel Analysis

Responses given below to the charge questions will often cover some of the same ground but is included here to be sure that a reader looking at any specific questions will receive a complete answer.

Question 1:

> How well does the 2016 report provided by DWR, "On Estimating Net Delta Outflow (NDO): Approaches to estimating NDO in the Sacramento-San Joaquin Delta" (the DWR report) respond to the State Water Board's request? That is, are the methods for estimating consumptive use and channel depletions and the underlying data and methods the best available?

NDO vs NDOI

The initial 1995 Bay-Delta Plan indicated that DWR was then in the process of developing new channel depletion estimates and subsequent updates have reinforced the need for better depletion estimates. The 2016 DWR Report lists multiple concepts to provide improved channel depletion but has suggested only that the DICU estimates be incorporated into the calculations along with other minor improvements. The State Water Board request to DWR was specifically for:

> "…its best available estimates of Delta consumptive uses and channel depletions, the data and methods underlying those estimates, and a recommended method for estimating net Delta Outflow *in real time* on a *daily* time scale."

NDOI in its current form does not actually estimate NDO, regardless of the depletion estimate used; but estimates net flow potential out of the Delta by estimating the Delta inflows minus estimated net channel depletion and diversions. The net channel depletions are done on a monthly time step. No effects of filling and draining within the Delta are included from transient offshore stage changes, wind fetch setup, or spring-neap cycles. During low flow periods in the Delta these effects can be on the same order as estimated NDOI, leading to small or negative net Delta outflows while NDOI suggests that regulations of outflow are being met.

The Report comparison of NDO versus NDOI in Figure 2 uses only a single year, 2002. It is not clear why a more rigorous analysis was not presented. Water year 2002 was classified as dry, but more recent years have been even more stressful on the system. A recent analysis by Monismith (in preparation) for water years 2008-2015 demonstrates that NDO and NDOI produce similar answers and most differences are explained when filling and draining effects are considered.

The Panel fully understands the DWR reasoning for using NDOI for planning applications. When "Delta Outflow" is being used for future watershed planning scenarios, "Delta Outflow" needs to be in a form that can be used in optimization routines that not only account for Delta circulation patterns, but all the reservoir/gate/pump operations throughout both the State and Federal Projects. In this case, "Delta Outflow" needs to be inferred from the primary operational "knowns" for the optimization program: 1) inflows on the Sacramento River, 2) San Joaquin River, 3) the desired rates of export at the State and Federal pump facilities, and 4) climate patterns. This is why DWR argues on page 5, item 4 "NDOI is amenable to planning applications – given a hydrology, export, climate and land use pattern, DWR can produce a credible approximation for NDOI. This is not feasible with NDO."

The State Water Board needs to be aware of the effects of filling and draining and that the use of low NDOI values can lead to near zero, or even negative, short-term NDO.

The Report argues on page 5, item 1 "Existing ecological results are based on NDOI. There is no obvious reason why the higher frequency subtidal component added by observed NDO could improve these, or it if could why the current four flow monitoring sites would be appropriate. Downstream locations are wider and even harder for accurate measurements."

At first glance, DWRs argument seems reasonable. The degree to which any ecological parameter is linked to the nuances of which "Delta Outflow" parameter is used for this measurement should not be significant enough to warrant a heated argument over which approach to use during any "standard year." However, given that this statement comes after California has had four drought years in a row points to circumstances where the definition of "Delta Outflow" became a critical question for satisfying regulations in State Board D-1641.

In winter 2014, the flow and water quality objectives in SB D-1641 were relaxed for Delta Outflows so that outflows in July could be reduced from 4,000 cfs to 3,000 cfs, if exports were maintained less than 1,500 cfs. One primary justifications for reducing this "Delta Outflow" requirement was that conserving cold water storage in the major reservoirs became a high priority for salmon spawning temperature requirements below the major dams (State Water Resources Control Board 2014).

The Long-Term Operations Biological Opinions (LOBO) annual science review panel has struggled with a similar issue of dealing with reservoir operations/cold water pool management in the context of a new climate regime. The executive summary of the 2015 LOBO review panel report stated: "Four consecutive years of drought have tested the engineered limits of the Central Valley Project to meet California's co-equal goals of improving the reliability of water supply and protecting the Delta ecosystem. Current climate change predictions offer little reassurance that challenges will be less severe in the future. It may be time for all stakeholders to view their expectations in the context of a “new normal” climate pattern that constrains the availability of water resources, particularly cold-water reserves, in more years than might be expected from the historical record.” (Kneib *et al.* 2015). Similar to the cool water pool issue, we should expect low flow conditions to occur more frequently in the Delta. Therefore, the question of how to account for Delta Outflow in dry and critically dry years is important.

It is the opinion of this Panel that conditions may occur more frequently where the Delta must be managed in low “Delta Outflow” conditions and the incorporation of tidal influence in the Delta Outflow calculation for ecological applications would be appropriate.

There is evidence that filling and draining of the Delta does influence water quality. In a report funded by the State Water Board examining south Delta salinity, Fleenor and Ji (2011) found that the largest spikes in south Delta salinity were produced at the end of spring tides when the Delta would just start draining. The report found this to be a necessary but not always sufficient factor in the salinity spikes.

Channel Depletion

The Report provided some insight to the differences in three channel depletion estimates made by Dayflow, DICU, and DETAW. All three models include groundwater/seepage in depletion estimates. DICU is an improvement over the Dayflow approach because DICU includes spatial variability throughout the Delta based on crops in 142 sub-sections and seasonal variability of applied flows. However, precipitation is not represented well in this model. Sporadic rainfall events lasting only a few days in the wintertime are a major source of water. The DICU method outputs at a monthly time step. In the program accounting method, total precipitation for a month is available all month. Therefore, if a storm occurred at the end of the month, the accounting program considers that precipitation to be available at the beginning of the month. According to the Report “this can cause underestimation of excess precipitation and runoff, particularly large, sporadic events.” While precipitation errors are not likely to occur at low flow periods in the Delta, averaging diversions over months will affect estimates of NDOI.

Table 1 Comparison of channel depletion calculators

	DETAW	**DICU**	**Dayflow**
Output time step	Daily	Monthly	Monthly
Channel Depletion based on:	168 sub-regions (they are almost the same as the 142 DICU regions)	142 sub-regions	Monthly gross Delta depletions values based on one DWR analysis (1965)
Precipitation	Runs on a daily time step which can represent daily values of sporadic run-off events	Total precipitation for a month is available throughout that month. It does not account for when the precipitation occurred.	
Location representing precipitation	Nine CIMIS stations weighted for each sub-region using Polygons	Five meteorological stations around the Delta are weighted for each-sub-region using Thiessen Polygons	Stockton Fire Station #4: Applied to the total acreage of the entire Delta
Land-Use Distribution	Two land-use distributions 1) Dry/Critical Years (based on 1976) 2) Wet/Above/Normal/Below Normal (based on 1992-2002 composite)	Two land-use distributions 1) Dry/Critical Years (based on 1976) 2) non-critical (based on 1970s/1980s)	No land-use distributions
ET Estimates based on:	SEBAL		The depletions do not vary based on water year type.
Groundwater considered?	No	No	No
Year Model developed	2006	1995 (published report)	1978

The explanation of DETAW in the Report is incomplete requiring the reviewers to research the Kadir (2016) report to fully understand the approach. One Panel member was familiar with the DETAW work, through a pilot project funded by the State Water Board to produce improved Delta channel depletion estimates (Siegfried *et al.* 2014). The focus of Siegfried *et al.* (2014) was to improve understanding of diversion and return locations, apply GIS based properties to diversion and return locations, and use GIS based land-use data easily updated in an automated framework. Although the research (Siegfried 2012) was provided to DWR by the State Water Board, it was not included in the Report. Discussion of DETAW does not clarify the graphs provided which show adjusted- and unadjusted-DETAW estimates.

It is unclear why DWR has chosen to implement the use of DICU rather than move toward daily estimates from DETAW. The Report states “different from DICU, DETAW has been calibrated and validated based on independent estimates of net consumptive use …”. No rationale is given for not recommending DETAW. Section 2.6 provides a quantitative comparison between Dayflow, DICU and DETAW but there is little commentary or systematic analysis explaining these differences.

Groundwater

The effect of groundwater, or seepage, cannot be quantified without direct measurement of diversions and returns, along with accurate estimates of consumptive use. The Integrated Water Flow Model (IWFM) identified in this section utilizes a newer consumptive use tool as a demand calculator, IDC. The IDC calculator was used in the pilot project by Siegfried *et al.* (2014) on the recommendation of DWR. Siegfried et al. (2014) preformed all work in close cooperation with DWR to make it as useful and relevant to DWR as possible. If insufficient data currently exist for the application of IWFM (or similar model) then it should have been discussed in the Report as a barrier to refining the estimates.

Land Use Data

Since the consumptive use calculators used in Dayflow, DICU, and DETAW incorporate lumped crop types it is not clear why this section lists 254 crops. The Report recommends the use of DICU for NDOI calculation. DICU uses 20 crop classes and only two land use years. For dry and critical years, it uses land use data from 1976 and for other year types it uses data from the late 1970s-early 1980s. It is unclear from the Report whether DICU output is compromised by using data that is over 45 years old and would be changed significantly under prevailing climate conditions and land uses.

Direct NDO Measurements

The Panel agrees with the finding in the Report that the direct measurement of NDO is challenging due to the fact that it requires the summation of four independent, tidally-influenced index-velocity stations. However, based on ongoing research and analyses in the Bay–Delta and elsewhere, the conclusions related to the accuracy of ADCP measurements expressed in the Report are overly pessimistic. The challenges are formidable and include: extracting a small residual flow from large tidal flows (signal-to-noise), rating accuracy, measurement accuracy, data gaps, data availability, short-term variability (on the order of days to weeks), and negative values (when the Delta is filling). The Workshop on Delta Outflows and Related Stressors Panel (2014) states “Although a precise estimate of the accuracy of the measured outflows is not known, the measured values should be more accurate than NDOI as long as the four monitoring stations used in the calculations are operating properly”. This statement is not substantiated with analysis; however, it does suggest a level of confidence in the results. The more recent work of Monismith (in preparation) determines that NDO measured by current monitoring stations is of the same accuracy as NDOI with differences accounted for by sub-tidal frequency processes that contribute to Delta filling and draining.

The DWR Report identifies the following specific challenges:

- Extracting a small residual from large tidal flows (“signal-to-noise”)
- Index-velocity rating accuracy
- Measurement accuracy

These challenges are well-know and DWR, USGS and others have ongoing work to address these issues.

Extracting a small residual from large tidal flows ("signal-to-noise"). Simpson and Bland (1999) found that the accuracy of the net discharge was on the order of 0.5% of the peak tidal flows at Threemile Slough. If the errors among all index velocity stations in the Sacramento-San Joaquin Delta are consistent, then the error in the net flows would be on the order of +/- 500 cfs at Rio Vista and +/- 750 cfs at Jersey Point.

Index-velocity rating accuracy. Index-velocity calibration techniques are well documented (Ruhl and Simpson 2005, Levesque and Oberg 2012). As the DWR Report suggests, there may be additional ways to improve ratings at individual stations using more advanced statistical techniques or exploring the possibility of using paired transects in rating development.

Measurement accuracy. There has been significant work on the accuracy of the moving-boat discharge measurement approach (Oberg and Mueller 2007, Mueller *et al.* 2013, LeCoz *et al.* 2016). The accuracy of individual discharge measurements in a tidal environment is perhaps more difficult to quantify as the reference discharge is not constant over the measurement period. However, measuring transects using boat-mounted acoustic Doppler current profilers (ADCP), Oberg and Muller (2007) found that the error associated with individual discharge measurements is typically within +/- 5% or less. The errors associated with these discrete measurements should be random and non-biased ensuring that the resulting computed discharge is also non-biased with a lower overall error.

Multiple Control Volumes

The Panel determined that Multiple Control Volume Method could be a useful tool to: 1) identify sub-regions where consumptive uses and channel depletions are estimated by DICU or DETAW are in error, and 2) identify flow measurement stations that need improvement by comparing results to nearby stations. The Report is too short on specific details of this method to fully judge its efficacy.

Salinity Inversion

During low flow periods the focus is often on salinity intrusion into the Delta. Measurement of salinity will likely always be more accurate and less expensive than measurement of flows. The use of well-calibrated, three-dimensional models with salinity measurements could be more cost efficient than other methods. The Report has not fully examined the salinity inversion techniques, regression work or direct attempts at assimilating field data with simulations performed to date (*e.g.*, MacWilliams *et al.* 2015).

The inversion example given uses a single location for salinity, Martinez. Considering the asymmetric distribution of salinity of ebb and flood tides, multiple locations and consideration of flow direction would certainly provide a better answer (Chen 2015). In fact, regressions may not be the appropriate solution. Ongoing work with an integral model may prove more worthwhile than regressions (Stephen Monismith pers. comm.).

Question 2:

Does the DWR report provide a firm technical basis for its key conclusions and recommendations? Specifically, the following conclusions and recommendations from pages 1-2 of the DWR report:

a. A water balance approach similar to the Net Delta Outflow Index (NDOI) remains the most suitable tool to define net Delta outflow for regulatory purposes, but should be updated to incorporate improvements to consumptive use estimates and correct a few known water accounting errors.

The Report clearly demonstrates that DWR has done considerable work in attempting to find better ways to estimate net Delta outflow, however each method still requires more work to demonstrate whether they are worthwhile. The Report does not systematically compare the other methods to determine which is the best NDO estimate, but simply recaps the work done on each and the weaknesses of each method. The conclusion is then made that the NDOI approach, with some modifications, remains the best regulatory tool. The only direct comparison is for NDOI as predicted by the various net depletion differences in Dayflow, DICU, and DETAW.

The initial 1995 Bay-Delta Plan indicated that DWR was then in the process of developing new channel depletion estimates and subsequent updates have reinforced the need for better depletion estimates. The DWR Report reviewed multiple concepts to provide improved NDO estimates but have suggested none of them for implementation. The State Water Board request to DWR was specifically for:

> "…its best available estimates of Delta consumptive uses and channel depletions, the data and methods underlying those estimates, and a recommended method for estimating net Delta Outflow *in real time* on a *daily* time scale."

NDOI in its current form does not actually estimate NDO, but estimates net flow potential out of the Delta by estimating the Delta inflows minus estimated net channel depletion and diversions. Net channel depletions are done on a monthly time step. No effects of filling and draining within the Delta from transient ocean water surface elevation changes, wind fetch setup, or spring-neap cycles are estimated. During low flow periods in the Delta these effects can be on the same order as estimated NDOI, leading to small or even negative Delta outflows.

b. The Delta Island Consumptive Use model (DICU) is the most mature consumptive use estimate, and should be used to calculate NDOI until an improved daily model, such as DETAW, is sufficiently validated and officially released.

DICU has been used by DWR as inputs to hydrodynamic modeling of the Delta for many years. It is unclear why DWR is reluctant to use DETAW rather than DICU. The Report states "different from DICU, DETAW has been calibrated and validated based on independent estimates of net consumptive use …". Both still suffer from groundwater/seepage unknowns and unknown lags between diversion and returns.

In the Report, Figure 20 on page 23, DICU significantly over-predicts NDOI when compared to the Dayflow and DETAW methods in August and September of a dry year, 2014.

c. Direct measurement of net Delta outflow using the United States Geological Survey (USGS) acoustic Doppler current profiler (ADCP) stations at Rio Vista, Jersey Point, Dutch Slough, and Threemile Slough is inaccurate, and should not be used.

The assessment of acoustic measurement accuracies has some merit in that tidal asymmetries and channel sizes pose significant challenges. However, these limitations can be partially overcome with greater attention. Further, recent analysis has demonstrated that direct measurement and current Dayflow estimates have comparable accuracies, with timing differences explained by sub-tidal frequency cycles of filling and draining the Delta (Stephen Monismith, pers. comm.).

When the focus is on real-time monitoring of salinity intrusion into the Western Delta during extreme drought conditions, the “Delta Outflow” value of most interest is the value from observed monitoring stations in the Delta. Here, the NDO is the most appropriate “Delta Outflow” because it accounts for the influence of tides on the hydrologic balance (*i.e.* the filling and emptying of the Delta) in real-time conditions.

Because the magnitude of the currents and tidal stages vary over the fortnightly spring-neap tidal cycle, residual currents, and thus transport, vary on this timescale as well. During the transition from neap to spring tides, the Delta fills, while during the transition from spring to neap, the Delta empties.

The filling and draining of the Delta has been observed both in field sampling programs and hydrodynamic numerical modeling simulations. Oltmann (1995) showed that during low flow periods, the flows associated with the filling and emptying of the Delta over the spring-neap tidal cycle are comparable to typical summer flows.

Monsen (2001) estimated the influence of filling and draining with a two-dimensional hydrodynamic numerical modeling simulation of the Delta for November 1999, a period of time when the combination of tides, gate operations, pump operations and low-flow conditions caused extremely high salinity concentrations in the Western Delta. During that time period, the tidally-averaged stage value along both the main stem Sacramento and San Joaquin varied up to 25 cm over the spring-neap tidal cycle. Based on the model bathymetry grid, the surface area of the Delta above Chipps Island is approximately 2.3×10^8 m^2 at mean sea level. The volume of the Delta above Chipps Island at mean sea level is 1.3×10^9 m^3. Based on these values, a 25 cm rise in stage results in an approximately 5.7×10^7 m^3 increase in Delta volume, a 4.5% increase. This is equivalent to about a 100 m^3/s (~3,500 cfs) flow in and out of the Delta over the spring-neap cycle attributable to tides alone.

DWR argues on page 5, item 3, “Much of the filling and draining is caused by offshore events with a short prediction window compared to travel time from Oroville and Shasta. These oscillations are a natural variation that cannot be resisted or negated with flow from upstream. DWR is wary of the operational practicability of any short term standards that includes this information.”

It is true that some major factors that contribute to filling and draining are changes in wind and atmospheric pressure. Lacy (2000) has shown that fluctuations in wind stress and wind setup can cause changes in water surface elevation on the order of 20 cm in Suisun Bay.

While wind and atmospheric events are short enough in duration that they cannot be counter-acted with water releases from Oroville and Shasta, some consideration on diversions could be given. However, the timing of the spring-neap tidal cycle is known and could be accounted for in operations during extreme low-flow periods.

d. More studies are needed.

The Report clearly demonstrates that DWR has done considerable work in attempting to find better ways to estimate net Delta consumption, however all require more work to demonstrate whether they are worthwhile.

Question 3:

Do the two additional net Delta outflow estimation methods described in the report, the Multiple Control Volume Method (pp. 31-32) and salinity inversion method (p. 37), hold promise for future use as outflow estimation tools?

The Panel determined that Multiple Control Volume Method could be a useful tool to: 1) identify sub-regions where consumptive uses and channel depletions as estimated by DICU or DETAW are in error, and 2) identify flow measurement stations that need improvement by comparing results to nearby stations.

The Multiple Control Volume method, however, would not result in a tool to produce a "Delta Outflow estimation." The Delta is a very unique system where every sub-region has its own hydrologic characteristics. Gate operations, temporary barrier placement, export pump operations, and storage in flooded islands can control circulation patterns in each sub-region and these controls are constantly changing. At any given time, there is a high probability that some sub-regions will not be represented well in the Multiple Control Volume method and, therefore, the ending "Delta Outflow" calculation would still have inherent inaccuracies and the increase in Control Volume considered merely adds more uncertainties into the calculation. A systematic analysis would shed greater light onto the initial promise shown by this method.

Considering the DWR concerns surrounding accuracy with acoustic flow measurements described in the Report, it is unclear why DWR placed so much effort (claimed effort, not actually demonstrated) in the multiple control volume analysis, particularly as the details of this effort were not described clearly in the Report. The Panel recommends that further analysis is conducted and presented to compare with estimates generated by the use of the four downstream stations by themselves.

The Report has not fully examined the salinity inversion techniques and work performed to date. Measurement of salinity will likely always be more accurate than flows; and the use of well-calibrated, three-dimensional models with salinity measurements could be more cost efficient than other methods. These hydrodynamic models are calibrated so that they can simulate the distribution of salinity based on observations from the extensive monitoring network and USGS field sampling in Suisun Bay and the Delta.

MacWilliams *et al.* (2015) used the UnTRIM model to calculate a continuous location of X2 based on the model salinity vertical profiles. By using the model, the location of X2 is more directly located rather than interpolated between field salinity stations. Using a Dayflow calculation approach, MacWilliams *et al.* (2015) found a relationship between Delta Outflow and X2 that improves upon the relationship of Monismith *et al.* (2002). In theory, if the location of X2 is known, then Delta Outflow can be closely estimated based on the hydrodynamic simulation.

There are still some modeling considerations that would need be resolved before using this type of approach for calculating Delta Outflow, especially in low flow conditions. For instance, both DSM2 and UnTRIM incorporate monthly DICU estimates into their calculation of circulation. Second, in the X2-Delta Outflow equation in the UnTRIM model, when X2 is upstream of the junction of the Sacramento and San Joaquin Rivers (X2>75), X2 is assumed to be an average of the X2 intrusion on the Sacramento stem and the X2 on the San Joaquin stem. This assumption produces inaccuracies under low flow conditions.

Question 4:

> What are the panel's recommendations for improvements to the report? Based on the panel's knowledge of flow management in the Bay-Delta or other estuarine systems, what additional information, methods, or research are needed to improve net Delta outflow estimates?

The Report lacks specific technical background in most sections. Daily NDO estimates based on a Dayflow type of accounting will require much better information on diversions, returns and consumptive use along with adjustment for filling and draining associated with short-term sea level variability, wind fetch, and spring-neap tide cycles. Likely the only way to get better estimates is through direct metering of diversions and returns and consumptive use estimates from emerging remote sensing techniques and higher resolution meteorology within the Delta. Salinity will always be more easily and accurately measured than flow rates. Coupled with well-calibrated three-dimensional models, flow can possibly be more accurately estimated from salinity inversion techniques. However, the models will also suffer from lack of accurate in-Delta water use.

The Panel concurs with the Report on possible future directions, particularly the innovative approaches initiated by the Water Master, enhanced monitoring of diversions and return flows and better understanding of the connections between groundwater and surface water. The Panel would go further with these recommendations. The Delta and its watershed is subject to multiple stressors, including climate change (particularly the increased variability of conditions and likely higher frequency of extreme events), sea-level rise, land use changes and potential landscape-scale changes introduced through restoration actions. The Delta is dynamic and responds rapidly to these changing stressors. Therefore, strategies of estimating NDOI and NDO should avoid undue reliance on past conditions to predict the future (Milly *et al.* 2008). Since it is probable that it will be a decade or more before another full update of the Bay-Delta Plan, careful consideration should be given to adaptive integration of emerging technologies. In particular, for operational decisions and short-term actions, ways of stream-lining simulations and data processing should be considered. This does not necessarily mean simplifying the models or employing computational techniques such as Artificial Neural Networks that rely solely on historic conditions – but rather investigating new technologies in parallel with the traditional and tested approaches. These technologies could include expanding the use High-Performance Computing (HPC) and data assimilation tools to run within existing models.

Recommendations

Since the Report was developed, several additional studies and papers have become available. The Panel recommends this new information be considered in the continuing development of NDO and NDOI.

Regarding the use of downstream stations for the measurement of NDO, the Panel recommends the continued use of the farthest downstream stations until a more reliable and tested technique is proven, especially in dry and critically dry water years. These stations currently best characterize the tidal influence on water transport in the western Delta where the Sacramento and San Joaquin Rivers converge.

Examination of changing measurement protocols should be considered for improving measurement accuracy (*e.g.*, USGS protocol in riverine environments calls for paired or grouped transects).

The Workshop on Delta Outflows and Related Stressors Panel (Reed *et al.* 2014) recommended that the State Water Board consider implementing a longitudinal array of top and bottom salinity sensors. The Panel also suggest that such data would be of benefit to any flow and salinity regulations that they can envision.

The accurate and defensible determination of NDO and NDOI continues to prove a challenging target, despite more than 3 decades of effort. The complexity of the issue and the many innovative approaches being considered makes this a difficult goal to achieve for one agency, despite the very high level of expertise in modeling, monitoring and data interpretation sustained within DWR. In particular, if the State Water Board wishes to achieve the stated objective of ‘a recommended method for *estimating net Delta outflow in real time on a daily time scale’* (described in Panel Charge), a new approach needs to be adopted. The Panel recommends that this task would be an ideal application for a Delta Collaborative Analysis and Synthesis (DCAS) activity as called for in the Delta Science Plan (Delta Stewardship Council 2013). This synthesis activity would bring together a team of modelers, the leaders of current monitoring programs with postdoctoral researchers and dedicated scientists to (a) refine the methodology, (b) identify the most significant gaps in data currently, (c) conduct a monitoring campaign to close the elusive water balance for the Delta, and (d) be prepared as a community of experts to advise water managers and regulators on annual planning and for near real-time projections in times of crisis (such as droughts, floods, or levee failure).

If pursued, this activity could be a testbed for some of the principles called for in the recent 2016 report (Medellin-Azuara *et al*. 2016) that summarized recommendations from the "Integrated Modeling for Adaptive Management of Estuarine Systems" Workshop.

This endeavor would require resources in terms of funding for field studies and data processing, postdoctoral researchers to pursue uncertainty analyses and simulations, and the time of the best experts from agencies, universities, NGOs and the private sector that have experience to offer. The outcome would be an assessment of Net Delta Outflows, developed by a diverse team of scientists that provides the best available estimate, a quantification of uncertainty, a transparent list of assumptions, and where appropriate a summary of legitimate but dissenting minority opinion on the NDO and NDOI estimates for a given year or a short-term projection. This information can then be used to inform future State Water Board decisions.

Documents supplied to Panel

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