Fish and Water Management Tool Project Assessments: Record of Management Strategy and Decisions for the 2006-2007 Water Year

K.D. Hyatt and M.M. Stockwell

Fisheries and Oceans Canada
Science Branch, Pacific Region
Pacific Biological Station
Nanaimo, BC
V9T 6N7

2010

Canadian Manuscript Report of Fisheries and Aquatic Sciences 2913

Fisheries and Oceans   Pêches et Océans

Canada

**Canadian Manuscript Report of
Fisheries and Aquatic Sciences**

Manuscript reports contain scientific and technical information that contributes to existing knowledge but which deals with national or regional problems. Distribution is restricted to institutions or individuals located in particular regions of Canada. However, no restriction is placed on subject matter, and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Manuscript reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1-900 in this series were issued as Manuscript Reports (Biological Series) of the Biological Board of Canada, and subsequent to 1937 when the name of the Board was changed by Act of Parliament, as Manuscript Reports (Biological Series) of the Fisheries Research Board of Canada. Numbers 1426 - 1550 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Manuscript Reports. The current series name was changed with report number 1551.

Manuscript reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

**Rapport manuscrit canadien des
sciences halieutiques et aquatiques**

Les rapports manuscrits contiennent des renseignements scientifiques et techniques ques qui constituent une contribution aux connaissances actuelles, mais qui traitent de problèmes nationaux ou régionaux. La distribution en est limitée aux organismes et aux personnes de régions particulières du Canada. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du ministère des Pêches et des Océans, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports manuscrits peuvent être cités comme des publications complètes. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports manuscrits sont résumés dans la revue *Résumés des sciences aquatiques et halieutiques*, et ils sont classés dans l'index annuel des publications scientifiques et techniques du Ministère.

Les numéros 1 à 900 de cette série ont été publiés à titre de manuscrits (série biologique) de l'Office de biologie du Canada, et après le changement de la désignation de cet organisme par décret du Parlement, en 1937, ont été classés comme manuscrits (série biologique) de l'Office des recherches sur les pêcheries du Canada. Les numéros 901 à 1425 ont été publiés à titre de rapports manuscrits de l'Office des recherches sur les pêcheries du Canada. Les numéros 1426 à 1550 sont parus à titre de rapports manuscrits du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 1551.

Les rapports manuscrits sont produits a l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

Canadian Manuscript Report of
Fisheries and Aquatic Sciences 2913

2010

FISH AND WATER MANAGEMENT TOOL PROJECT ASSESSMENTS: RECORD OF MANAGEMENT STRATEGY AND DECISIONS FOR THE 2006-2007 WATER YEAR

by

K.D. Hyatt and M.M. Stockwell

Fisheries and Oceans Canada
Science Branch, Pacific Region
Pacific Biological Station
Nanaimo, BC V9T 6N7

© Her Majesty the Queen Right of Canada, 2010
Cat. No. Fs 97-4/2913E ISSN 0706-6473

Correct citation for this publication:

Hyatt, K.D., and Stockwell, M.M. 2010. Fish and Water Management Tool project assessments: Record of management strategy and decisions for the 2006 - 2007 water year. Can. Manuscr. Rep. Fish. Aquat. Sci. 2913: ix + 65 p.

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

TABLES

FIGURES

ACKNOWLEDGEMENTS

The operational deployment and testing of the Fish-and-Water Management Tools decision support system (hereafter identified as FWMT) in the Okanagan during 2006-2007 was made possible by the dedication and hard work of many individuals from several organizations:

- Richard Klinge and Bob Clubb from Douglas County Public Utility District (DCPUD) in Washington State provided not only monetary support but also the necessary confidence to implement multiyear trials to determine fish production benefits that may be achieved through deployment of a new generation of fish-and-water management tools.
- Deployment and testing of FWMT is executed under the authority of the three-party (Fisheries & Oceans Canada-DFO, BC-Ministry of Environment-MOE, Okanagan Nation Alliance-ONA) Canadian Okanagan Basin Technical Working Group (COBTWG) chaired by Steve Matthews (MOE).
- Brian Symonds of BC-Water Stewardship Division (WSD) continues to inject technical expertise and advice based on decades of experience as a “front-line” manager of the Okanagan Lake and River System.
- Don McKee and Des Anderson of the WSD Office in Penticton shared the role as “manager of record” during the 2006-07 water year.
- Andrew Wilson from BC-MOE Fisheries provided advice regarding status and trends for brood-year 2006 kokanee spawning and egg or alevin incubation at Okanagan Lake beaches.
- Deanna Machin, of the Okanagan Nation Alliance, ably administered the “umbrella” contract providing financial support to various program components from DCPUD. We also thank Pauline Terbasket for providing policy guidance on behalf of the ONA when required.
- Kari Long, Howie Wright and staff members of the Okanagan Nation Alliance Fisheries Department collected field information under contract on a range of indicators that inform FWMT elements in real-time or to verify FWMT utility.
- Paul Rankin and Barry Hanslit from DFO helped design and execute acoustics, trawl and survey work associated with assessing annual to seasonal production variations of juvenile sockeye salmon in the Okanagan River and Osoyoos Lake.
- Clint Alexander of ESSA Technologies Ltd. always made himself available to repair code “bugs”, investigate problems, and carefully explain the intricacies of FWMT software and the model to new and experienced users.
- Mark Shao of the Water Survey of Canada (Vancouver, BC) always provided immediate attention to transmission problems originating with WSC real-time hydrometric gauges or their server.
- Finally, congratulations are due to all members of the 2006-2007 FWMT Operations Team who demonstrated that exceptional levels of interagency and inter-party collaboration have the potential to produce exceptional levels of success for integrated resource management.

ABSTRACT

Hyatt, K.D., and Stockwell, M.M. 2010. Fish and Water Management Tool project assessments: Record of management strategy and decisions for the 2006 - 2007 water year. Can. Manuscr. Rep. Fish. Aquat. Sci. 2913: ix + 65 p.

The fish-and-water management tools (FWMT) system is a coupled set of 4 biophysical models of key relationships (among climate, water, fish and property) used to predict consequences of water management decisions (represented in a fifth decision-rules model) for fish and other water users in the Okanagan valley. At the beginning of each month from January 2007 to June 2007, updated snow survey reports from the BC Ministry of Environment River Forecast Centre were entered into FWMT. Snow reports included measurements of current snow-packs, recent climatic conditions, and forecasts of the magnitude and timing of future water runoff. FWMT use facilitated integration of these data with real-time information on fish stocks plus river and lake conditions to predict the impacts of a range of water storage and release scenarios for fish and other water users. FWMT scenarios were reviewed by an Operations Team to support an ongoing dialogue during the 2006-07 fish-and-water year regarding prudent water management decisions.

Through most of 2007, water management options were constrained by sub-average inflows to, and low water levels in Okanagan Lake. An extremely dry summer in 2006 necessitated minimal releases at Penticton Dam through the fall and early winter to maximize water conservation in the lake. Winter brought snow accumulations that were slightly above the all-year average suggesting that the spring freshet would bring Okanagan Lake to full pool and produce ample water storage for summer needs. However, by mid-May the water management outlook of FWMT users had shifted to consideration of a possible drought when approximately 50% of the predicted runoff, associated with the April 1 RFC forecast, failed to reach the basin. Water conservation to maximize storage in Okanagan Lake remained a priority for the remainder of the spring and summer of 2007.

Development of FWMT Scenarios and maintenance of an ongoing dialogue among its users in 2006-2007 resulted in a water management regime that satisfied the requirements of fish and other water users such that: (1) little risk materialized for loss of kokanee eggs or alevins prior to spring fry emergence at Okanagan Lake beaches, (2) sockeye eggs and alevins, incubating in the Okanagan River near Oliver, were not subjected to any acute dewatering or scour events, (3) water managers shifted quickly from consideration of freshet-driven flood risks through April to identification of potential summer drought conditions and an emphasis on water conservation starting in May, and (4) potential reductions to survival and growth of sockeye fry rearing in Osoyoos Lake in 2007 were avoided due to the early identification, in mid-May, by FWMT users, of an immediate need for water conservation measures. The subsequent ability of managers to initiate a supplemental release of stored water in mid-September reduced the severity of

potential impacts on sockeye fry of an acute temperature-oxygen “squeeze” that developed in the hypolimnion of Osoyoos Lake in late summer.

RÉSUMÉ

Hyatt, K.D., and Stockwell, M.M. 2010. Fish and Water Management Tool project assessments: Record of management strategy and decisions for the 2006 - 2007 water year. Can. Manuscr. Rep. Fish. Aquat. Sci. 2913: ix + 65 p.

Le système d’outils de gestion des eaux et des poissons (Fish-and-Water Management Tools System - FWMTS) est une série couplée de quatre modèles biophysiques de relations clés (le climat, les eaux, les poissons et la propriété entre autres) utilisé pour prédire les conséquences de décisions de régularisation des eaux (représentées dans un cinquième modèle de règle de décision) sur les poissons et d’autres utilisateurs de la ressource dans la vallée de l’Okanagan. Au début de chaque mois, de janvier à juin 2007, des relevés nivométriques mis à jour du Centre de prévisions des régimes fluviaux du ministère de l’Environnement de la C.-B. ont été entrés dans le FWMTS. Les relevés nivométriques comprenaient des mesures récentes des stocks nivaux, les conditions climatiques récentes et des prévisions du volume et du moment de l’écoulement futur. Le FWMTS a facilité le regroupement de ces données avec les données en temps réel sur les stocks de poissons et les conditions du lac et de la rivière afin de prévoir les effets d'une vaste gamme de scénarios de stockage et d'apport d'eau sur les poissons et d'autres utilisateurs de la ressource. L'équipe d'experts a examiné les scénarios pour appuyer le dialogue soutenu durant l’année 2006-2007 en ce qui touche la prise de décisions prudentes de régularisation des eaux.

Pendant la majeure partie de 2007, des débits entrants inférieurs à la moyenne dans le lac Okanagan et les faibles niveaux des eaux dans le lac ont limité les options de régularisation des eaux. Un été extrêmement sec en 2006 a nécessité la réduction au minimum des débits au barrage Penticton pendant tout l’automne et au début de l’hiver afin de conserver le plus grand volume d’eau possible dans le lac. L’hiver s’est soldé par des accumulations de neige légèrement plus abondantes que la moyenne annuelle, ce qui permettait de croire que la crue printanière amènerait le lac Okanagan à sa capacité maximale et produirait un volume amplement suffisant d’eau stockée pour répondre aux besoins en été. Cependant, à la mi-mai, les utilisateurs du FWMTS ont commencé à considérer la possibilité d’une sécheresse lorsque 50 % environ de l’écoulement prévu, selon les prévisions du Centre de prévisions des régimes fluviaux du 1er avril, n’a pas atteint le bassin. La conservation de l’eau afin de maximiser le stockage de la ressource dans le lac Okanagan est demeurée une priorité pendant le reste du printemps et à l’été en 2007.

Le développement de scénarios à l’aide du FWMTS et la poursuite du dialogue entre ses utilisateurs en 2006-2007 ont résulté en un régime de gestion des eaux qui

satisfaisait aux exigences des poissons et d’autres utilisateurs de la ressource de sorte que : (1) peu de risques de perte d’œufs ou d’alevins vésiculés de kokani avant l’émergence des alevins au printemps sur les plages du lac Okanagan se sont matérialisés, (2) les œufs et les alevins vésiculés de saumon rouge, en incubation dans la rivière Okanagan près d’Oliver, n’ont pas été soumis à un assèchement aigu ou à l’affouillement, (3) les gestionnaires des ressources en eau ont rapidement passé de la considération de risques d’inondation imputables aux crues jusqu’en avril à l’identification de conditions de sécheresse estivale potentielle et à la priorité accordée à la conservation de l’eau à partir de mai, et (4) la possibilité de réduction du taux de survie et de croissance des alevins de saumon rouge dans le lac Osoyoos en 2007 a été évitée grâce à l’identification précoce, à la mi-mai, par les utilisateurs du FWMTS, d’un besoin immédiat de mesures de conservation de l’eau. La capacité résultante des gestionnaires de procéder à un apport supplémentaire d’eau stockée à la mi-septembre a permis de réduire la gravité des impacts potentiels, sur les alevins de saumon rouge, de la compression température-oxygène aiguë qui s’est développée dans l’hypolimnion du lac Osoyoos à la fin de l’été.

INTRODUCTION

Significant declines in Okanagan sockeye salmon (*Oncorhynchus nerka*) production have occurred during several intervals over the past 50 years in spite of curtailment of both marine and freshwater harvest (Hyatt and Rankin 1999, Stockwell and Hyatt 2003). In Canada, this issue has become a focus for activities of the Okanagan Basin Technical Working Group (COBTWG) which is composed of representatives from Canada's Department of Fisheries and Oceans (DFO), the British Columbia Ministry of Environment (MOE) and the Okanagan Nation Alliance (ONA). In 1998, Douglas County Public Utility District (DCPUD) expressed an interest in working with COBTWG to increase production of Okanagan sockeye salmon. Increased sockeye production constitutes a DCPUD mitigation requirement of their Federal Energy and Regulatory Commission (FERC) license (and, more recently, their Habitat Conservation Plan) associated with operation of the Wells hydropower dam on the Columbia River in Washington State (Bull 1999).

Personnel from DCPUD identified an emphasis in their terms of reference for pursuit of stock enhancement or restoration options that would provide:

- readily quantifiable benefits,
- sockeye salmon production benefits of about 100,000 smolts per annum,
- an economically attractive opportunity relative to alternate approaches,
- potential to achieve regulatory approval by several levels of government, and
- project development and operational deployment within 3 years or less.

The COBTWG acknowledged these requirements and provided additional criteria based on their commitment to the conservation and restoration of Okanagan fisheries resources within an "ecosystem based management framework". These criteria included:

- restoration activities that would provide benefits at the single species level to sockeye and at the ecosystem level to other, high value, indigenous fish species (i.e. provide ecosystem benefits),
- manipulations of fish or habitat that would be amenable to formal risk assessment as one component of benefit-cost analysis,
- application of an adaptive management process for manipulations of fish or habitat (i.e. adaptive management involves adoption of an incremental approach to project implementation, a commitment to assessment and monitoring prior to, during and after project completion and cyclical review of information to make key decisions).

Following review of various project options (Bull 1999) and further consideration of the criteria above, a consensus emerged among COBTWG members by 2001 that a water management option (Fish-and-Water Management Tools Project) was their top priority given that:

- analyses by Summit Environmental (2002) and Hyatt *et al.* (2001) indicated changes to water management practices had the potential to increase average, sockeye production by roughly 15%,
- costs to achieve this increase were economically competitive with other options (e.g. spawning channel development),
- implementation of the water management option could be achieved within the context of the existing Canada-BC, Okanagan Basin Water Agreement (i.e. no special regulatory approvals were required to implement water management actions contemplated under this option),
- initial development, testing, refinement and deployment of an FWMT decision support system could be completed within 3-4 years,
- provision of decision support tools to key resource managers (i.e. fish and water managers) to improve water management practices for sockeye production would also provide benefits for other high value fish species such as kokanee (*Oncorhynchus nerka*) or rainbow trout (*O. mykis*),
- knowledge of fish-water interactions was sufficiently advanced to support formal risk assessments of potential changes in water management procedures for fish and other water users, and
- alterations to seasonal water storage and/or release practices could be implemented through an adaptive management procedure.

FWMT SYSTEM CONTEXT

The Okanagan River and associated valley-bottom lakes (Figure 1) are managed as a water storage and regulation system, with most of the storage (340 $Kdam^3$) provided by Okanagan Lake as regulated by the control structure at the city of Penticton, B.C. Minor additional storage is provided in headwater reservoirs of smaller tributary streams (principally for domestic and agricultural use) and in Skaha and Osoyoos lakes. Key considerations in the regulation of the Okanagan Lake and River System (OLRS; Hourston *et al*. 1954) include:

- minimizing flooding damage around Okanagan Lake and along the Okanagan River downstream of Okanagan Lake,
- protection of fisheries values (e.g. Okanagan River sockeye eggs and alevins and Okanagan Lake shore-spawning kokanee, their eggs and alevins),
- satisfying domestic and irrigation water supply demands,
- support of recreation, navigation, and tourism by maintaining acceptable water levels for boat docks, launching-ramps and for river-float tourist businesses.

The Okanagan Basin Agreement (OBA; Anon. 1973) emphasized protection of the local sockeye salmon population because it was one of two remaining viable sockeye populations in the Columbia River system, and the only salmon population spawning and rearing principally within the Columbia River basin in Canada. Sockeye salmon spawn in October in the Okanagan River between Vaseux and Osoyoos lakes, principally in the 5 km of river immediately downstream of Vaseux Lake (Stockwell and Hyatt 2003). Egg and alevin development to swim-up occur between October and early May (Hyatt and Stockwell 2007). Sockeye fry rearing occurs in the north basin of Osoyoos Lake on a year-round basis (Hyatt and Rankin 1999).

Okanagan River flows can affect the sockeye population in the following ways:

- migration to the spawning grounds may be impaired (with resulting pre-spawn mortality and/or reduced gamete viability) as a result of flows that are excessively high or low,
- high summer flows due to melting snow-pack and coldwater input from the Similkameen River into the Okanagan River downstream of Osoyoos Lake reduce water temperatures (Hyatt and Stockwell 2003) which may influence mortality during upstream migration from Wells Dam pool to Osoyoos Lake,
- eggs and alevins may be impacted (physical damage and inability to survive in the water column) if redds are scoured as a result of flood control water releases during the pre-emergence incubation period,
- eggs and alevins can be desiccated if incubation period flows are reduced excessively from flows during the spawning period,
- seasonal distributions, growth, and survival of sockeye fry rearing in Osoyoos Lake are influenced by temperature and oxygen conditions modified by changes in the quality and quantity of Okanagan River inflow.

In order to mitigate these impacts, the Canada-British Columbia Report on the OBA (Anon. 1973) specified preferred fishery flows for the Okanagan River at Oliver (Table 1).

A review by Bull (1999) suggested that between 1983 and1998, water management decisions frequently departed from compliance with seasonal lake elevation and preferred river discharge levels recommended by the OBA. Discussions with “front line” fisheries and water managers in several FWMT workshops held during 2000-2003 suggested that difficulties in maintaining OBA compliance (Okanagan Basin Study 1974, OBIB 1982) were related to the complexity of balancing fisheries, flood control and water allocation benefits through the year, given large uncertainties in:

- forecasts of annual and seasonal water supplies,

- the exact timing of salmon life history events (spawning, egg incubation, etc.) that control their vulnerability in a particular year to losses from flood-and-scour or drought-and-desiccation processes,
- the magnitude of fish losses likely to be caused by deviations from recommended lake level or river flow ranges (e.g. during flood or drought conditions; Summit 2002),
- risk of “significant property” losses associated with seasonal maintenance of “fish friendly” lake elevation and river discharge levels given either flood or drought events.

FWMT SYSTEM DESCRIPTION

During 2001, the Canadian Okanagan Basin Technical Working Group (COBTWG) initiated a fish and water management tools (FWMT) project (Hyatt *et al*. 2001) to develop a set of quantitative, decision-support models to reduce uncertainties and improve the basis for water management decisions that influence annual production variations of fish. Creation of a user friendly, decision support system involved several phases of work including:

- a data and information assembly phase (ongoing since 2001),
- a fish-and-water management “business analysis” phase (2001-02),
- a models and information processing tools design phase (2002-03),
- a models and system tools building phase (2003-04), and,
- a testing and refinement phase (2004-present, see Alexander and Hyatt eds. 2005 for complete documentation of the FWMT system).

The resultant FWMT decision support system (Figure 2) and associated software provide a multi-user, gaming environment based on a set of five, coupled, “state-of-the-science” sub-models. FWMT software resides on a common server accessed through standard web-browser technology. FWMT users represent natural resource managers from private industry, First Nations, federal and provincial interests. Detailed descriptions of the design and functional properties of the FWMT system can be found in either the FWMT User Manual (Alexander *et al*. 2008) or the draft Record of Design document (Alexander and Hyatt eds. 2005). However, briefly here, seasonal variations in precipitation, air temperature, and water temperature serve as common drivers of four biophysical models (Figure 2). These models deal with climate and hydrology interactions, air and water temperature interactions, timing of kokanee spawning and egg incubation success at Okanagan Lake beaches, plus timing and success of sockeye salmon life-history events initiated with spawning in the Okanagan River in mid-October and concluded 14 months later in the winter prior to smolt migration from Osoyoos Lake.

Okanagan water management rules reflecting the contents of the OBA and historic practices of water managers are formalized in a fifth, water-management, “rules” model. The latter facilitates FWMT user-specified, choices among seasonal water storage or release options that influence socioeconomic and ecological risk factors or events (Table 2). These occur at several sites distributed from Okanagan Lake and the city of Kelowna in the north to Osoyoos Lake and the town of Osoyoos in the south near the Canada-U.S. border (Figure 1).

The 5 coupled sub-models represent a synthesis of quantitative, cause and effect relationships (among climate, water supply variations, fish, infrastructure and property) used to predict the consequences of seasonal to daily water management decisions for fish and other water users including:

- kokanee production outcomes in the upper watershed (Okanagan Lake),
- sockeye salmon production outcomes in the lower watershed (Okanagan River, Osoyoos Lake) and,
- damage and economic losses associated with urban and agricultural infrastructure and property under flood or drought conditions at riparian locations bordering the Okanagan River and valley bottom lakes.

FWMT can operate in retrospective-mode on historical data sets, in real-time-mode on current data, or in prospective-mode on synthetic-futures data to allow resource managers to identify decision options to solve complex fish-and-water management problems. Of particular relevance here, when used in real-time-mode, the FWMT system automatically loads hourly data once a day on Okanagan Lake and River elevations, water temperature and flows to a database through satellite links from multiple sites (Okanagan Lake, Penticton Dam, Okanagan River at Penticton, Okanagan River at Oliver, etc.). These data drive various sub-models and inform a suite of approximately 50 indicators that help FWMT software users interpret changes in water management risk factors (Table 2). Most indicators are available within the FWMT application during use as model predictions (P) or measured observations (O) (see “Source” section of Table 2). In addition, other diagnostics information may be retrieved through a tab-and-menu design that allows connection of FWMT users to various url-sources of site-specific indicator observations. Examples are: daily observations of accumulated snow-pack from Mission Creek or Brenda Mine snow-pillows, daily rainfall at Environment Canada meteorological stations in the Okanagan valley, and hourly discharge at Water Survey of Canada sites such as Mission Creek or Inkaneep Creek.

Although most indicators may be routinely accessed from within the FWMT application, a group of at least 14 additional indicators are acquired from sources outside of the application (see “Outside FWMT” section of Table 2). For example, riparian property owners and members of other non-government organizations often communicate their preferences to resource managers about the maintenance of particular seasonal patterns of lake levels or river discharge. Although the OBA specifies seasonal patterns and priorities for management of such patterns, regional concerns regarding perceived risks of flooding, drought, loss of fisheries or recreational values do serve as general “pressure indicators” that managers consider when employing particular FWMT scenarios as a basis for specific decisions. Similarly, ongoing field assessment activities, supported by the FWMT project, provide key indicators to verify whether FWMT predictions are a reliable basis for fish-and-water management advice. Thus, seasonal sampling programs to document the timing, duration, or outcome of particular biophysical events (e.g. use of spawning habitat by adult sockeye, timing of sockeye fry emergence, etc.) provide an array of important status and trend indicators. These indicators are used to inform in-season use of the FWMT application (e.g. confirm FWMT prediction that sockeye fry are clear of flood-and-scour risk associated with decisions to increase discharge above egg/alevin scour thresholds). They are also used for post-season assessments of fish-and-water management outcomes (e.g. fish production or economic value gains or losses associated with FWMT use).

FWMT designers recognized from the outset that the complexity of sub-model interactions, numeric output, and scores of potential indicators could limit the utility of FWMT to target users (i.e. front-line, fish-and-water managers). To overcome this problem, system software provides a user friendly interface that converts complex numeric outputs from model simulations into key performance indicators (e.g. sockeye egg or fry losses; dollar value of insurance claims for flood damage etc.). FWMT performance indicators are expressed in a graphical form that follows a familiar “traffic-light” principal (green = go ahead; amber = exercise caution; red = stop or risk certain damage). The graphical user interface (GUI) and traffic-light indicators largely eliminate requirements for managers to identify precise numeric outcomes to achieve prudent water management decisions.

FWMT was first put into use in 2004-2005 (Hyatt and Bull 2007). In this report, we review the performance of FWMT during its third year of operational use and testing in 2006-2007. The purpose of the report is to provide a record of:

- environmental conditions and selected traits of the subject fish stocks at the start and then throughout the 2006-2007 fish-and-water management year (October 2006 to November 2007),
- the sequence of water storage and release strategies necessitated by climate variations in the Okanagan during the October 2006 through September 2007 portion of the water management year,
- experience with in-season use and testing of the FWMT system,
- advice and management options identified by the FWMT operations team,
- subsequent actions taken by water managers and their outcomes,
- strengths and weaknesses of FWMT as a decision support system, and

- recommendations for changes or refinements to either FWMT or processes supporting its use by the FWMT Operations Team (OT).

In the near term, this information will be used to refine both FWMT application software and OT effectiveness. In addition, this record of management strategy (ROMS) report will contribute to a multi-year assessment due in 2013. The assessment will determine whether deployment of FWMT has contributed to conservation and restoration objectives for the subject salmon populations (Okanagan River sockeye salmon, Okanagan Lake kokanee salmon).

HYDROLOGY AND WATER MANAGEMENT IN THE OKANAGAN BASIN

The Okanagan is a snowmelt-dominated system, with a spring freshet that occurs from April through June, accounting for as much as 90% of the annual inflows (Dobson 2004). By July, the freshet declines and inflows to the system remain low for the summer, fall, and winter. Because of the arid to semi-arid climate in the valley, most summer precipitation evaporates or soaks into the ground and does not contribute directly to surface water flow.

The wide fluctuations between spring and summer flows are tempered dramatically by water regulation. Okanagan Lake receives about 80% of all surface water draining into the Okanagan Basin and has sufficient capacity to store 100% of this inflow in one out of three years and at least 66% of the inflow in eight out of ten years. However, in roughly one in four years, characterized by above average snow-pack, the equivalent of 50% or more of freshet inflows must be released to avoid flooding. Storage during spring runoff reduces the risk of flooding and retains water for release later on, during lower flow periods. With a surface area of 35,000 hectares and a preferred operating range of 1.22 m, Okanagan Lake can store up to 420 million cubic meters of water (Canada – British Columbia Okanagan Basin Agreement, 1974). This capacity is usually sufficient to regulate preferred seasonal levels in Okanagan, Skaha and Osoyoos Lakes as well as the volume and the timing of flows in the Okanagan River.

Water released from Penticton Dam at the outlet of Okanagan Lake flows south down the Okanagan River through Skaha and Vaseux lakes before entering Osoyoos Lake and then proceeding south for 124 km to join the Columbia River (Figure 1). Several tributary streams join the river between Okanagan and Osoyoos lakes. For most of the year their contribution is relatively small, but during a wet spring, their composite volume can add as much as 57 cms to discharge released from Okanagan Lake (BC Lands, Forests & Water Resources, 1975). A more complete description of the hydrology of the Basin can be found in Glenfir Resources (2006).

Water storage reduces the risk of flooding, ensures an adequate water supply is available for use in the dry summer months, and provides suitable lake levels for kokanee and river flows for returning sockeye. The decision of how much water to store at any particular time is not an easy one. During spring freshet, the amount of water entering the system far exceeds the amount that can be released through the dam at the outlet of Okanagan Lake. Therefore, the lake must be lowered before freshet to a level sufficient to store most of the freshet inflows. When inflows exceed the volume of storage plus outflow, billions of dollars worth of real estate may be flooded. On the other hand, if the lake is drawn down too far prior to freshet, resultant summer water shortages will not satisfy both irrigation and aquatic ecosystem needs.

High levels of coordinated effort are needed to: estimate the storage requirement for any particular year, manipulate lake levels and river flows to match uncertain climatic conditions, alter decisions constantly to keep up with changing circumstances and trade off gains and losses among a wide range of interest groups. An annual operating plan provides targets for lake levels and river flows at various times of the year but the volume of incoming water varies tremendously depending on snow-packs and climatic conditions. This challenges adherence to the annual plan and compliance with fisheries provisions of the Canada-BC Okanagan Basin Water Agreement (Bull 1999). FWMT use facilitates water regulation decisions by providing timely field information and by demonstrating, in advance, likely outcomes of alternate management decisions (Hyatt and Bull 2007, Hyatt *et al*. 2009).

MODIFICATIONS TO THE FWMT USER INTERFACE FOR 2006 - 2007

During the initial two years of working with the FWMT, operators identified a number of additions or refinements to the Tool that would help to make it more “user friendly” as well as less time consuming while running simulations (Hyatt and Bull 2007, Hyatt *et al*. 2009). In response, several elements of FWMT software were modified for use in 2006-07 (Alexander *et al*. 2008). Major modifications to the FWMT User Interface included the additions of “Narratives” and “Diagnostics” tabs, along with “User-Specified Inflows” and “Help” functions.

<u>Narratives Tab</u>

The Narratives feature provides a message forum for FWMT users to share scenarios, results, or other pertinent information that may affect in-season water and fisheries concerns in the Okanagan system. Team members may post messages or replies, along with support documents to the Narratives tab to share key information including:

- commentary regarding the rationale behind individual water release strategies;

- biological updates (e.g. sockeye and kokanee start-up parameters or field observations of egg hatch or fry emergence timing);
- imminent changes to weather or environmental conditions that could significantly influence lake level and/or river discharge rates (e.g. rapid onset of snow melt indicating pending flood hazard, or updates of conditions that anticipate onset of a temperature-oxygen “squeeze” in Osoyoos Lake); or
- technical problems and outcomes (e.g. errors from real-time data sensors or technical malfunctions of Water Survey of Canada or FWMT servers).

When a new water year begins, all entries to the Narrative during the previous water year become un-editable. Thus, the Narrative becomes a permanent archive of important events and key management decisions made throughout the year to inform mid- and post-season reviews.

Diagnostics Tab

The “Diagnostics” tab allows rapid access to external web sites that supply local or regional weather forecasts and real-time environmental data (*e.g.* snow pillow status, lake levels, river and tributary discharge rates) without having to exit the model. These sites provide FWMT users with updates of conditions that influence current and near term inflow and discharge patterns - valuable information which helps to guide decisions for setting outflow constraints. In particular, any information that may provide insight into the timing and magnitude of the spring freshet is extremely beneficial when attempting to balance flows between flood avoidance and fisheries requirements (scour prevention) during a weekly to daily time window. The onset and rate of snow melt can often be ascertained from changes in real-time snow pillow data (snow depth, snow-water equivalents, air temperatures >0°C), increasing runoff in tributaries to Okanagan Lake or River (e.g. Mission Creek, Vaseux Creek), and local weather forecasts.

Additionally, regional trends in snow-pack and weather patterns provide FWMT operators with insight into whether they should place more weight on the average, low or high River Forecast Centre (RFC) inflow forecasts when making decisions about outflow constraints.

User Specified Inflow Estimates

Total inflow estimates determined by the RFC drive the predicted outcomes within the FWMT model. However, these estimates are not fully reliable because they are based on limited available data (i.e. current conditions at the 1st of each month) which are then projected across one to several months. RFC estimates assume that average weather patterns will persist throughout the forecast period. The user specified inflow function permits entry of revised inflow estimates between monthly forecasts as needed. The capacity to revise inflow estimates greatly improves the ability of FWMT users to plan water release strategies that are responsive to rapidly changing weather conditions and inflow patterns (e.g. at times when unexpected weather systems contribute significant snow accumulations, heavy rainfall or warmer temperatures that accelerate snow melt and runoff).

User specified inflow estimates are also valuable at times when RFC forecasts are delayed. For example, if a current RFC estimate is not entered into the FWMT at the beginning of each month (February to May), the system employs an all year average inflow estimate to predict outcomes. Average default values will be highly inappropriate in exceptionally wet or dry years.

Help Function

The addition of a Help menu provides FWMT users with quick links to several on-line support documents and tools, as well as contacts for technical assistance. One of the more frequently accessed documents is “The Apprentice Guidebook” (Alexander *et al*. 2008) which serves as the Okanagan FWMT user’s manual.

METHODS

DEPLOYMENT AND IN-SEASON USE OF FWMT

The authority for fish, habitat, and water management decisions in British Columbia is shared between Canada’s Department of Fisheries and Oceans (DFO) and the Province of British Columbia’s Ministry of Environment (BC-MOE). The Okanagan Nation Alliance (ONA, a First Nation government) also is involved and has a constitutionally guaranteed access to fisheries resources for food, ceremonial and societal purposes. Consequently, fish-and-water management decisions involve the exercise of delegated authority by personnel in each of several federal, provincial and First Nation groups. Participation of key personnel from these groups is essential to the development and routine use of any decision support tools involving fish-and-water management. In consideration of this, the three party Canadian Okanagan Basin Technical Working Group (DFO, BC-MOE and ONA) formed a FWMT project steering committee to act as a source of “agency” expertise and authorizations for FWMT system deployment, testing, and refinement.

FWMT system use is incorporated into a stepwise pre-season, in-season, and post-season process as follows:

Pre-season Process

1. The FWMT Steering Committee meets in the late summer to early fall to confirm Operations Team (OT) lead members and alternates for the upcoming fish-and-water management year.
2. OT members review the management cycle and activities from the previous year and recommend changes or refinements to either the FWMT system or OT processes (Hyatt and Bull 2007; Hyatt *et al*. 2009).

In-season Process

3. The FWMT system is initialized with "startup" values (e.g. Hyatt *et al*. 2007) for year-specific sockeye and kokanee numbers and biological traits (spawner abundance, start, peak and end spawning dates; sex ratio, magnitude of egg deposition, etc.). In the absence of snow-pack and annual water yield predictions prior to February 1st, default all-year average snow-pack and water-yield values are used within FWMT to create a startup base-case to identify an "expected" seasonal water management pattern for Okanagan Lake levels and Okanagan River discharge (e.g. seasonal predictions in Figure 3).
4. The BC River Forecast Centre conducts snow surveys at the beginning of each month from January through June with small additional surveys on May 15th and June 15th. Within about a week of the survey, a regional analysis is made of the snow-pack information to provide a prediction of the amount of water that will enter the system for the year. Estimates are provided for an average forecast, a low forecast (1 standard deviation lower than the average), and a high forecast (1 standard deviation higher than the average) on Feb. 1st, March 1st, April 1st and May 1st in a given fish-and-water cycle year.
5. By approximately the 10th day of the month, a member of the OT enters the inflow forecasts into FWMT where it is combined with real-time field information (e.g. daily values for discharge and water temperature imported automatically from Water Survey of Canada hydrometric stations).
6. Between the 10th and 15th days of the month, individual OT members access FWMT through the internet and run a series of simulations or "scenarios" to predict effects of various release and storage patterns on fish (sockeye and kokanee salmon) or other water users (irrigators, recreational boaters).
7. OT members then review risk factors (Table 2) and potential impacts associated with either flood or drought conditions that a given water-management scenario suggests may affect socioeconomic or ecological elements or events throughout the valley.

8. FWMT users initially interpret the likelihood of impacts from a given risk factor or process by examination of whether key indicators (flood risk in Okanagan Lake, sockeye egg-scour risk at Oliver, etc.), portrayed in graphical output from a given FWMT-scenario, exceed hazard thresholds set to warn of moderate (amber) to acute impacts (red).
9. At their discretion, users may then examine supplementary sources of pressure, status and trend indicators (Table 2), accessed from within or external to the FWMT application, to reach an informed opinion about the potential risk and impacts associated with an impending water management decision.
10. Scenario(s), supplementary indicator observations, and interpretive materials are generally shared among OT members via direct e-mail communication or by accessing support information submitted by and for users within the Narratives table accessible within the FWMT application (Alexander *et al*. 2008).
11. Around the middle of the month, OT members teleconference to discuss projected outcomes from the subject scenario(s) and whenever possible, to reach consensus on the preferred flow release plan for the next interval lasting several days to a month.
12. In times of rapidly changing climatic conditions and inflow patterns, OT members run scenarios, confer and then make decisions to change release patterns whenever necessary – sometimes as often as every few days.

<u>Post-season process</u>

13. In October or November a “post-season review” meeting is held to consider RFC inflow predictions, inflows observed, water release decisions, and associated outcomes.
14. Following the post-season review meeting, a report of: FWMT scenarios developed, indicators used, advice provided, decisions made, outcomes achieved and recommendations for the future is assembled in a word document to provide an annual record of the performance of both the FWMT System and the Operations Team.

RESULTS

PRE-SEASON MANAGEMENT STRATEGIES

A pre-season FWMT meeting was held in Penticton on December 13, 2006 to review the outcomes of 2005-2006 (see Hyatt *et al*. 2009) and to discuss the outlook and operational procedures for 2006-2007. Discussion relative to the latter included:

- the overall, strategic objective for the year (i.e. manage water storage and release decisions such that kokanee and sockeye salmon would be afforded protection from undue lake level or discharge variations without incurring significant increases of collateral damage to other interests from flood or drought events),
- a new, priority objective which emphasized the requirement for advance planning for storage of late-summer, contingency water in Okanagan Lake - water that could be released in order to avert the development of a temperature-oxygen squeeze in Osoyoos Lake (Hyatt *et al*. 2009),
- appointments to the FWMT Operational Team (Table 3),
- kokanee and sockeye salmon start-up parameters (see Hyatt *et al*. 2007)
- new refinements to the Tool (Diagnostics, Narrative and Help features; user defined inflow estimates),
- Options for long-term web-hosting of FWMT

IN-SEASON DECISIONS

Details regarding all in-season events, FWMT Team discussions, flow release decisions and outcomes are documented in Table 4. Key decisions, events, and outcomes are identified in Figure 4.

October - December 2006

At the initiation of the 2006-2007 water year, Okanagan Lake was approximately 15cm below the fall target level (341.90m) recommended for kokanee spawning (Figure 3A). This low level was the result of four months of extreme negative inflows caused by prolonged hot, dry weather (Figures 5 and 6). The FWMT-OT identified preservation of the current Okanagan Lake level as a priority in order to (a) protect beach spawning kokanee from desiccation risk and (b) ensure the lake would re-fill to meet the summer 2007 targets should dry conditions persist through the winter. Accordingly, spills at Penticton Dam, were reduced from 11 to 4 cms at the end of October (Figure 4B) when sockeye spawning was complete. Releases at Penticton were maintained to yield no less than 5.5cms (50% of spawning flows) downstream near Oliver to afford sockeye eggs and alevins protection from desiccation or stranding (OBAI 1982; Table 1; Figure 4D).

During routine FWMT runs near the end of November, some users (Stockwell, Wright) noticed that extremely low discharges (~3cms) near Oliver had triggered an amber hazard warning on the sockeye egg performance bar. As daily air temperatures had been <-10°C for nearly a week, sustained flows of this rate would expose sockeye redds along gravel bar margins and subject them to rapid freezing. Don McKee of Water Stewardship was contacted and he immediately identified the problem as icing of the WSC hydrometric gauge at Oliver creating false readings (Figure 7). True flows had not fallen below the recommended 5.5cms.

<u>January 2007</u>

Early season snow pillow readings showed normal to above normal conditions with an overall snow water index of 110% for the Okanagan-Kettle basin (Figure 8). However, sub-average precipitation and weekly net inflows to the lake persisted into the winter of 2007, prolonging the dry conditions throughout the region (Figures 6 and 9). November and December net inflows to Okanagan Lake were only 40% of all-year average inflows. Despite reduced spills, Okanagan lake level continued to drop and by January was approximately 20cm below the winter benchmark (Figure 4A). Sub-zero temperatures in mid-January again posed a risk for a small portion of sockeye eggs associated with redds located in shallow side channel areas. Field-site inspections suggested risk of major egg losses were minimal so water conservation remained a priority and Water Stewardship continued to maintain Penticton releases at minimal levels.

<u>February 2007</u>

By February, the water supply outlook appeared more optimistic. Snow-pack in the Okanagan basin remained normal to above normal (Figure 8). The RFC forecast was 540 $kdam^3$ or approximately 103% of the all year average (Table 5) and precipitation and inflows had increased during the month to volumes that were within normal winter ranges (Figures 6 and 9). The additional inflows together with sustained low spill rates prevented further declines in Okanagan Lake level. By mid-month, the lake level was on a trajectory that would put it slightly above the February 25^{th} benchmark of 341.7m - the target level that denotes the initiation of spring drawdown. Given the snow conditions noted above, both fisheries and water managers were now anticipating average to somewhat above average inflows resulting from spring snow-melt. Therefore, the OT agreed that it would be prudent to begin drawing the lake closer to the month-end target in advance preparation for the run-off. The additional drawdown would be slight and have no impact on kokanee survival. Water Stewardship commenced increases in spill at Penticton Dam during mid-February such that discharge reached 16cms by the end of the month. Unregulated tributary inputs downstream at Oliver were negligible so that even with the additional spills, spawning ground flows remained well below the scour threshold (Figure 4D).

<u>March 2007</u>

Throughout the winter and into the spring, regional snow-packs continued to follow the same pattern - Mission Creek snow pillow remained equal to the all year average while Brenda Mine was 10-15% above the normal (Figure 8). The March RFC inflow estimate fell in line with the all year average (Table 5). Precipitation and corresponding weekly net inflows to Okanagan Lake were near or somewhat above seasonal norms. Consequently, the spring snowmelt was still expected to yield average net inflows to the lake.

The OT held a teleconference call on March 26th to discuss a water release strategy for the approaching freshet season. Water Stewardship (McKee) related that Okanagan Lake was >10cm above the April 1st target level of 341.55m. As spring inflows were expected to be average to above average, he recommended increasing spills to 18-20cms (currently at 15-17) in order to draw the lake down closer to the April benchmark. This would create additional storage space for the anticipated, elevated runoff and prevent possible risk of flooding around the lake. However, he expressed concern that an amber warning was triggered on the kokanee development bar in FWMT scenarios incorporating even small increases in discharge rate (Figure 10).

The OT noted that the snow pillow status from October to mid-April of the current water year was very similar to the snow status during the same time period for the previous year (Figure 8). DFO (Hyatt) recalled that in 2006 there was an unexpected, significant accumulation of high elevation snow late in the season (Figure 8A). This was quickly followed by rapid melting which in turn, triggered elevated flood threats and hence, the necessity to radically increase spills beyond the scour threshold (>60cms at Oliver; Hyatt et al. 2009). Additionally, during 2007 the remainder of the Province was experiencing record high snow packs suggesting the likelihood of escalating snow accumulations in the Central Interior. Hyatt recommended immediately increasing spills to 20-24cms to ensure the lake was drawn closer to the spring target, thereby avoiding potential “panic releases” and undue scour to sockeye alevins should an unexpected late accumulation of snow occur. He noted that continued protection of kokanee through low water releases would place a much higher proportion of sockeye at risk in May. MoE Fisheries (Wilson) responded that kokanee emergence was nearing completion and any risk to remaining alevins from additional drawdown would be minimal; therefore, Water Stewardship should commence the suggested increase in spill.

Despite the higher spills advised for precautionary measures, the OT expected that seasonal runoff would refill Okanagan Lake to full pool (342.54m) by June 24th. Water Stewardship increased releases at Penticton Dam to approximately 22cms by the end of March.

<u>April 2007</u>

Regional weather patterns continued to be unremarkable. Snow pillow readings and RFC inflow estimates remained relatively unchanged with respect to their relationships to all year averages (Table 5; Figures 8 and 9B). High elevation pillows continued to see the accumulation of snow throughout the month but intrusion of a warm-front in early April initiated rapid snow melt at lower and mid level elevations. This resulted in noticeable increases to unregulated tributary flows near Oliver. This triggered an FWMT amber hazard condition for sockeye redd-scour (Figure 10D). Water Stewardship responded by reducing spill at Penticton Dam (20 to16 cms) to ensure that downstream flows from the combined dam releases plus additional tributary inputs would not exceed the scour threshold of 28.3 cms at Oliver.

FWMT identified 100% kokanee fry emergence by mid-April and as indicated by the solid green performance bar, “kokanee friendly” lake objectives were preserved throughout their entire incubation period (Figure 4A).

By late April, the OT observed that new FWMT scenarios were producing amber and red hazard warnings on the sockeye alevin performance bar beginning the week of May 6th (Figure 11D). At this time, FWMT was predicting scour inducing flows at Oliver as a result of run-off induced increases in “predicted” unregulated tributary inputs. DFO (Hyatt) advised the OT that despite the FWMT prediction of high discharge at Oliver during May, actual risk of scour to sockeye alevins would be relatively low. Field sampling conducted throughout April and May indicated that true emergence was approximately two weeks ahead of the 100% emergence date predicted by the model (i.e. May 27, 2007; Figure 11D). Sampling results revealed that sockeye fry emergence had peaked near April 24th and then rapidly declined over the following week (Figure 12A). Fry emergence is normally complete within 8-14 days of the observed peak (Hyatt and Stockwell 2007) and thus, sockeye should be considered “safe” by approximately May 8th after which large increases in discharge would pose no risk to alevins. The discrepancy between predicted and observed fry emergence timing was concluded to be due to the fixed ATU method of determining sockeye development within the model (see discussion).

Towards the end of April, a regional cooling trend slowed low elevation snow melt and corresponding tributary inputs. High elevation snow melt had not yet begun. Okanagan Lake was rising more slowly than expected for the time of year but this was attributed to the recent overall reduction in inflow rates. These conditions allowed continuation of a spill rate of approximately 18cms at Penticton without exceeding 23cms at Oliver, so scour of sockeye redds was not a concern.

May 2007

Fyke net surveys in the Okanagan River identified the completion of sockeye fry emergence (~99%) on May 10th, approximately 1 week earlier than the FWMT prediction. Thus, “sockeye friendly” river flow objectives were successfully maintained from the time of egg deposition in October through to fry emergence (Figures 7 and 12).

At the beginning of the month, snow pillow and RFC outlooks continued to promise normal spring inflows to Okanagan Lake. However, by mid May, the situation had taken a surprising turn. It was evident to the OT that net water yield to Okanagan Lake was far below normal in spite of the persistence of "average to above average" snow conditions throughout the year. Water from snow melt was simply not reaching the lower valley. Unregulated tributary inflows, which are indicative of runoff, quickly peaked 2 weeks earlier than normal (May 16th) at unseasonably low rates (40-65% of normal), and then rapidly receded (Figure 4D). Inflows to Okanagan Lake had been somewhat below average since the week of April 22nd and then dropped to less than 50% of average by the end of May (Figure 9B). Okanagan Lake was refilling at a very low rate and was on a trajectory to be 25-35cm below full pool by the June 24th target date (Figure 13). Low elevation snowmelt was complete and high elevation snow-pack had decreased by 50%, offering little prospect of additional, significant inflows. Precipitation through April and May was less than half the norm and the Environment Canada weather office was predicting an increasing drying trend for the region (Figure 6).

Taking into consideration the current and prospective snow/water conditions, the OT agreed that the RFC mean estimate (400 $kdam^3$) for the May 1st to July 31st forecast was likely biased high. Remaining inflows from snowmelt and precipitation would more realistically fall closer to 1 standard deviation below the mean (i.e. 325 $kdam^3$; Table 5). New scenarios run with the lower inflow value in conjunction with reduced summer spills suggested that agricultural and domestic water intakes would be impacted by low water supplies (Figure 13C). Additionally, early drought-like conditions pointed towards the development of a severe temperature-oxygen "squeeze" that would compromise the survival of juvenile sockeye rearing in Osoyoos Lake (Figure 13D). The OT agreed that water conservation was an immediate priority. On May 27th, Water Stewardship scaled back releases to 8cms at Penticton Dam in an attempt to accelerate the refilling of Okanagan Lake for summer storage.

June - July 2007

High elevation snow accumulations peaked almost 2 weeks later than normal but melted rapidly during May and had completely dissipated by the beginning of June - approximately 1 month earlier than average (Figure 8). Total freshet inflows for May 20th to June 3rd (typically, peak runoff period) amounted to just 50% of the all year average. Despite the substantial spill reductions at Penticton Dam, Okanagan Lake was 32cm below full pool by the June 24th seasonal benchmark. Furthermore, with snow melt complete and Environment Canada forecasting a hot, drying trend, the OT believed that the lake would not reach the July 29th target level of 342.3m. Both fisheries and water managers raised concerns regarding the impending prospect of a severe water supply shortage in Okanagan Lake; specifically, water required to support summer irrigation withdrawals and fisheries requirements (i.e. Osoyoos Lake temperature-oxygen squeeze mitigation plus elevated river flows for adult sockeye migration and spawning) during late summer and early fall. On June 6th, Water Stewardship cut back spills (to 4cms) at Penticton Dam in order to maximize water conservation in Okanagan Lake. Unregulated inputs from tributaries downstream of Penticton supported continued flows of >8 cms downstream near Oliver.

The low spills triggered red and amber hazard readings for recreational flows in Penticton Channel (Figure 14B). However, preferred flows for recreation are of lower priority and are taken into consideration if there is a sufficient water supply and water requirements for all other needs have been satisfied. More notably, low flows triggered hazard warnings on the performance bars for agricultural and domestic water intakes downstream at Oliver (Figure 14C). Low discharge from Penticton Dam combined with elevated water extractions downstream brought flows to within levels that would dewater some intakes. Over the remainder of the summer, spills at Penticton were increased and adjusted as required to meet the needs of downstream irrigation intakes while conserving water in Okanagan Lake.

During late June and early July, a series of low pressure weather systems passed through the southern Interior providing cooler temperatures and contributing considerable amounts of much needed precipitation (Figure 6). The substantial inflow increases (Figure 9B) combined with water conservation measures, improved conditions enough such that Okanagan Lake fell just 3cm short of the July 29th target of 342.30m (Figure 4A). Nonetheless, the respite from dry conditions was short lived and net inflows rapidly returned to sub-average volumes by the end of July.

August - September 2007

The summer of 2007 continued to be extremely hot and dry throughout the Okanagan Valley. Limited precipitation, coupled with substantial water losses through evaporation and upstream irrigation withdrawals, resulted in very low water inflows to Osoyoos Lake. Given these conditions, fisheries managers were anticipating a significant reduction in juvenile sockeye rearing habitat[1] due to the development of a late summer, temperature-oxygen “squeeze” (Hyatt et al. in prep., Alexander and Hyatt 2005). By mid-August it was apparent that net inflow to Osoyoos Lake would not reach a cumulative July-September input of 145-160 million m^3 - the minimum volume required to avoid a temperature-oxygen squeeze event (Figures 15 and 16D; Alexander and Hyatt 2005). Consequently, the OT held a teleconference Aug. 20th to discuss the potential for creating a “pulsed flow event” in order to avert or at least offset the severity of the squeeze. The intention of the pulsed flow was to flush organic matter from the surface waters of Osoyoos Lake with the expectation that this would reduce organic loading and biological oxygen demand in the deeper waters of the lake. Discussion revolved around FWMT

---

[1] Optimal juvenile rearing habitat is the depth interval at which water temperature is <17°C and dissolved oxygen is >4ppm.

Scenario 452 (Figure 16) which identified sufficient water available in Okanagan Lake to support a two week pulsed release (up to 25cms) without drawing down the lake to levels that would, (a) compromise water storage for remaining summer irrigation requirements, (b) be below the preferred elevation for kokanee spawning in the fall, or (c) impact adult sockeye migration and spawning flow requirements. OT members concluded that a pulsed flow event was feasible given the current water supply in Okanagan Lake and agreed to initiate such an event in September (Table 4, advice of Aug. 20th).

Multiple field surveys to measure temperature and oxygen conditions in Osoyoos Lake revealed a progressive descent of the 17°C isopleth such that juvenile sockeye were restricted to depths below 15m by the beginning of August. However, the 4ppm O_2 isopleth remained stable near the lake bottom until the end of the month allowing sockeye continued access to the cooler, deep waters of the lake. Between the surveys of Aug. 26th and Sept. 4th, the 4ppm O_2 isopleth ascended rapidly to converge with the 17°C isopleth at a depth between 14 -15m, effectively confining juvenile sockeye to a narrow band (<1m deep) of habitable rearing area (Figure 17). DFO reported the field results to the OT and as previously agreed, water managers increased spills at Penticton Dam to 25cms for two weeks (Sept. 10th - 24th) in order to generate a pulsed-flow event into Osoyoos Lake. An immediate retreat of the 4 ppm oxygen isopleth to a depth of approximately 19m was observed in conjunction with the pulsed release (Figure 17). The volume of habitable water continued to expand over the next two weeks as the onset of epiliminial cooling (associated with cooler night time, air temperatures) coincided with the remainder of the pulsed flow event (Figure 17). Increasing divergence between the temperature and oxygen isopleths after Oct. 1st was associated with seasonal destratification of the lake.

DISCUSSION

Environmental conditions during water year 2006-2007 were fairly unremarkable and consequently, there were fewer challenges placed on the FWMT Operational Team than in previous years (Hyatt et al. 2009, Hyatt and Bull 2007). Through much of the year, water release options were constrained by sub-average inflows to, and low water volumes in Okanagan Lake. Therefore, the need for regularly scheduled teleconference calls was considerably reduced this year. Nonetheless, communication between OT members was maintained with regular e-mail exchanges and over 50 comments, replies, and scenarios logged in the FWMT Narrative record between October 2006 and September 2007.

Winter brought regional snow pillow accumulations that were normal to slightly above normal compared to the all-year averages. Through winter and early spring, Okanagan Lake remained close to target levels designated to accommodate spring runoff. After running and discussing multiple FWMT scenarios, all members of the OT were confident that inflows from snowmelt could be readily managed to avoid any risks of property and riparian damage from flood and collateral risk of scour to sockeye eggs and alevins. Additionally, they expected sufficient water inflows for Okanagan Lake to reach the full pool level required in early summer to satisfy late summer irrigation and fisheries requirements. However, by mid-May, expectations of an “average” water supply were replaced by conditions threatening summer drought. After 2 years of experience with FWMT, the majority of users had developed systematic schedules for running scenarios and checking diagnostics information (e.g. snow-pack, weather forecasts, tributary flows, etc.; Table 2) - commonly, on a weekly basis. This routine led to prompt recognition of this unexpected drying trend at a time when the BC-RFC was still forecasting average inflows and flood warnings were being issued for the Slocan Valley immediately southeast of the Okanagan Valley.

Given the contrary drying trend in the Okanagan, the OT recommended immediate reductions in spill at Penticton Dam in order to facilitate increased water storage in Okanagan Lake. This prevented significant water losses in Okanagan Lake that may have occurred if release decisions were based on just snow-pack data and RFC estimates. Ultimately, net inflows to the lake during peak spring run-off amounted to less than 65% of normal. Post season discussions with water management established that sub-average inflows may have been due to the “patchiness” of snow distribution across the watershed. Unevenness in snow depth and spatial coverage were observed during April helicopter surveys by the BC MoE (Don McKee, pers. comm.). Net inflow estimates are based on automated snow pillow readings from discrete locations and thus, may not always be representative of the region as a whole. Additionally, given the relatively dry conditions in the region over the previous 10 months, an above average proportion of run-off may have been lost to either sublimation processes affecting snow-pack or absorption of melt-water to ground before it reached tributaries to Okanagan Lake.

FWMT scenarios assembled from mid-May through Sept consistently identified a high risk of onset of an acute temperature-oxygen squeeze and reductions of habitat for juvenile sockeye rearing in Osoyoos Lake. Frequent discussions between DFO and Water Management (see details in Table 4) emphasized the need for aggressive steps to conserve sufficient water in Okanagan Lake to support an experimental, supplemental release of water as a potential “squeeze” mitigation action. Stringent water conservation coupled with a few fortuitous rain events enabled Okanagan Lake to reach late summer target levels. Subsequent, FWMT scenarios demonstrated sufficient water was available to meet summer irrigation requirements and to provide a two week “pulse release” of 20-25 cms of water to Osoyoos Lake (FWMT Scenarios 430, 432, 452; Figures 14-16). This action was initiated on the advice of DFO fisheries personnel after field sampling confirmed the onset of a severe “squeeze” between Aug 13th and Sept 4th (Table 4, Sept 25th commentary). Provision of supplemental flow appears to have resulted in an immediate expansion of the volume of sockeye rearing habitat in the offshore waters of Osoyoos Lake (Figure 17). The water volume considered suitable for sockeye rearing continued to expand as seasonal cooling set in.

Historic difficulties for water management compliance with OBA requirements to maintain “fish-friendly” flows (Bull 1999) originated from the complexity of balancing fisheries, flood control and water allocation benefits throughout the year given large uncertainties in:

- water supply forecasts,
- timing of salmon life history events and associated changes in their vulnerability to seasonal losses,
- the potential magnitude of losses given departures from OBA flows,
- risks of significant property losses under varying flood or drought conditions.

The FWMT decision support system and associated field assessments were designed to reduce these uncertainties and to increase the frequency of “fish friendly” water management decisions without incurring significant increases in property losses. Although there have been too few years of FWMT deployment to fully assess the magnitude of success for these objectives, results from 2006-2007 provide some clear examples of the value of FWMT use in managing risk factors affecting: kokanee salmon life history events and production in upstream portions of the Okanagan watershed, sockeye salmon life history events and production in downstream portions of the watershed (Okanagan River near Oliver and Osoyoos Lake), property and infrastructure in riparian sections of the Okanagan from Kelowna in the North to Osoyoos in the South.

From the time of kokanee salmon spawning in early October to emergence of their fry from Okanagan Lake beaches in March, FWMT scenarios allowed water managers to track daily variations in net inflows and water levels to avoid drafting Okanagan Lake below elevations that would potentially induce significant losses of eggs or alevins prior to spring emergence. Although, taken in isolation, this would appear to constitute simple avoidance of a 15 cm or greater elevation reduction from the time of kokanee spawning (early Oct) to fry emergence (March), this must be accomplished while “balancing” flow releases at the Penticton Dam to ensure sockeye salmon eggs and alevins downstream of Penticton Dam, near Oliver, are not subjected to flows that will induce sockeye egg/alevin scour or desiccation. During the fall-spring of 2006-2007, water levels maintained in Okanagan Lake remained within the low risk zone for kokanee eggs and alevins (Figure 4A). Similarly, although sockeye eggs/alevins were subjected to two desiccation risk events from freezing conditions in Nov 2006 and Jan 2007, followed by a potential scour event in late March (Figures 4D and 7), in-season information contained in several FWMT scenarios provided sufficient advance warning for water managers to take actions to avoid any significant losses of production. Consequently, flows at Oliver were maintained within a safe range defined by desiccation-event (minimum weekly flow of 5 cms) and scour-event drivers (maximum weekly flow of 28.3 cms) throughout the sockeye incubation interval (Figure 7). In addition, advance warning of the likely occurrence of a summer drought and a late summer loss of sockeye rearing habitat in Osoyoos Lake led to early decisions for aggressive water conservation steps. This enabled managers to execute an experimental release of supplemental flows to mitigate for sockeye rearing habitat losses induced by an acute temperature-oxygen squeeze event in Osoyoos Lake in Sept. 2007 (Figure 17). Finally, in spite of drought conditions that persisted throughout the spring and summer of 2007, water managers were able to employ FWMT to determine an appropriate balance for lake level and flow needs of fish versus those required to ensure recreational boater access to docks plus unimpeded water withdrawals at irrigation and domestic intakes at Okanagan Lake, Penticton Channel, Oliver Channel and Osoyoos Lake sites (Figure 4 A-D and Table 4).

Routine deployment and testing of FWMT software and support processes over the past two years have resulted in changes to both elements of the software and field programs supporting its use (Hyatt and Bull 2007, Hyatt *et al*. 2009). However, experience during 2006-2007 suggests continued room for improvement. The two most significant weaknesses emerging from FWMT use this year pertain to (a) the reliability of sockeye sub-model predictions of egg and alevin developmental timing and (b) the confusing nature of status and trend indicators designed to predict the onset and severity of temperature-oxygen squeeze events in Osoyoos Lake.

As observed in past years, a discrepancy in sockeye egg hatch and fry emergence timing was noted between FWMT model predictions and in-season field sampling results (Table 6, Figure 12). This discrepancy is due, in part, to the way in which sockeye and kokanee sub-models within FWMT treat the relationship between daily water temperature and the accumulation of thermal units (ATUs) to estimate 100% egg hatch (595 ATUs) and fry emergence (875 ATUs; Hyatt et al. 2007). The current incubation sub-models assume the developmental rate of salmonid embryos will vary lineally with temperature such that hatch and emergence timing may simply be determined by the summation of thermal units accumulated throughout the incubation period. However, past research suggests that at temperature extremes, developmental rates become markedly curvilinear. For example, developmental rate compensation of up to 800% occurs as temperatures fall from 4 to 0°C (Figure 18; Brannon 1987). During the winter as water temperatures in the Okanagan River approach 0°C, FWMT accumulation of thermal units drops precipitously and this prolongs the time to predicted sockeye hatch and emergence under the linear developmental rate assumption. However due to compensation, development is proceeding at a relatively rapid rate at these low temperatures.

The log-inverse Belehrádek formula (Beacham and Murray 1990) accounts for the non-linear effects of incubation temperature on development and may be used as a more reliable method to predict hatch and emergence timing. During the fall and winter of 2006-07, water temperatures were less than 2°C for more than 75 days resulting in low ATU values within FWMT. Consequently, FWMT predictions of 100%

hatch were approximately 6 weeks later than in-stream sampling observations revealed. Estimates based on the Belehrádek method were just over 1 week more than field observations (Table 6). In 2007, FWMT predictions of 100% fry emergence appear to be much closer to the observed and Belehrádek-derived dates (Table 6) because the additional ATUs accumulated during the warm spring counteracted the low winter values. However, during years of exceptionally warm winters or cool springs, predictions of 100% emergence based exclusively on a lineal model of ATU accumulation can introduce errors of more than 10 days (M. Stockwell, unpub. data).

Accurate prediction of fry emergence timing is especially critical during high inflow years when water managers must weigh multiple risks of releasing high flows too early to avoid scour-induced losses of incubating sockeye eggs/alevins versus prolonging moderate flows too long to avoid destructive flooding and damage to riparian properties. In such circumstances, water managers place a premium on knowing whether they might achieve a better balance of possible outcomes for fish and property by advancing or delaying elevated water releases by several days to a week. Consequently, improvements in any one of: predictions of future net inflows to Okanagan Lake, daily rates and trends in rates of inflow, egg hatch and fry emergence times are highly desirable. As the Belehrádek method provides more accurate results than the simple ATU method, it should be incorporated into future amendments to the FWMT model to predict sockeye hatch and emergence timing. By contrast, water temperatures in Okanagan Lake remain relatively stable even during sub-zero air temperature periods in winter. Consequently, the current sub-model assuming lineal ATU accumulation regardless of temperature range works well to predict kokanee hatch and emergence times and should remain the primary method to determine their developmental timing within the FWMT kokanee sub-model.

Previous information suggests that temperature-oxygen, “squeeze” events become acute in Osoyoos Lake and virtually eliminate ideal rearing conditions for juvenile sockeye if cumulative inflows between July and August are less than 145 million m^3 (Figure 15, Alexander and Hyatt 2008). Accordingly, the graphic representation of a squeeze event within FWMT has been portrayed as a plot of variations in the rearing volume of habitable water in Osoyoos Lake through time (Figures 13D, 14D, 16D). Osoyoos Lake is assumed to start the season with a maximum rearing volume of slightly more than 190 million m^3 which declines seasonally as surface waters warm and deeper waters become increasingly depleted of oxygen. The hazard thresholds during this decline were set arbitrarily at 40 million m^3 to trigger an amber warning and 20 million m^3 to trigger an acute red-hazard warning. However, FWMT users found it difficult to interpret habitat changes portrayed this way. Furthermore, although the FWMT graphics indicator would trigger a warning of the onset of an acute “squeeze” event, there was no logical code within the software to reverse an acute seasonal event once triggered. Consequently, even if users generated a scenario with sufficient spill of water to eliminate a “squeeze’ event, once induced, or if surface temperatures cooled sufficiently to re-establish useable rearing habitat, graphics output for the squeeze indicator remained refractive to such changes. By contrast, plots of actual temperature and oxygen isopleths provide a superior representation of the timing, extent, and seasonal dynamics of squeeze events in Osoyoos Lake (Figure 17). Consequently, future revisions to FWMT software should consider inclusion of a squeeze, hazard-indicator that reflects not only the development but also the relaxation of squeeze events under the influence of seasonal changes in Osoyoos Lake.

Finally, in each operational year, new and experienced users continue to identify opportunities to refine and improve FWMT software, as noted above, and Operations Team procedures for its use and maintenance. Table 7 identifies new problems encountered during the 2006-2007 water year and suggests recommendations for solving them.

GLOSSARY

Automatic Snow Pillow or ASP: A station where snow water equivalent and other parameters are measured automatically. The data collected are transmitted by satellite (generally every 3 hours). These sites are normally very remote with access by helicopter only.

Cumulative Precipitation: The total precipitation in a region since the previous November 1. Usually expressed as a percentage of normal.

Freshet: The substantial rise in water level of a stream or river caused by melting snow in the spring.

Fish and Water Management Tools Decision Support System: A computerized program for predicting the impacts of various water storage and release options on fish and property.

Hydrograph: A plot of the level or flow of a river over a period of time.

Normal: is the average value of a parameter over a fixed, usually 30-year period. At present the normal period is 1971-2000. Thus the normal water equivalent of a snow-course is the mean value for the 1971-2000 period, for that sampling date.

Regional Snow-pack Index: The sum of the snow-water equivalents at selected representative snow-courses in the region. Often expressed as a percentage of normal.

Scenario: An set of assumptions on the events that take place during a water year (October 1-September 30) in the Okanagan basin. The scenario includes information on water releases through Okanagan Lake dam, RFC inflow estimates and values for various fisheries variables such as peak spawning dates and the threshold total of accumulated thermal units for fry emergence.

Snow-course: A marked location, free from encroachment, where snow depth and snow-water equivalent are measured on a regular basis with standard snow sampling tubes.

Snow-water Equivalent: The water content of a snow-pack at a point, expressed as the depth of water that would result from melting the snow.

Tool – see Fish Water Management Tools Decision Support System

Water Year: The period of time from October of *year n* when sockeye and kokanee spawn, to early November of *year n+1* when salmon fry rearing is complete.

Volume Forecast: A forecast of the volume of water expected to pass a given point on a river (or flow into a lake) in a set time period. This is based on current and antecedent conditions, but assumes normal weather patterns through the forecast period. Units are usually thousands of cubic decameters ($kdam^3$), which is the same as millions of cubic metres.

LIST OF ACRONYMS

ATU	Accumulated Temperature Units
BC-MOE	British Columbia Ministry of Environment
DCPUD	Douglas County Public Utility District
DFO	Fisheries and Oceans Canada
ESSA	ESSA Technologies Ltd.
FWMT	Fish Water Management Tools System
IJC	International Joint Commission
Kdam³	thousands of cubic decametres = millions of cubic meters
m³/s	cubic metres per second
ONA	Okanagan Nation Alliance
WSC	Water Survey of Canada
RFC	River Forecast Centre

REFERENCES

Alexander, C.A.D., K. Hyatt and B. Symonds (eds). 2008. The Okanagan Fish/Water Management Tool: Guidelines for Apprentice Water Managers (v.2.1.000). Prepared for the Canadian Okanagan Basin Technical Working Group, Kamloops, BC and Douglas County Public Utility District, Wenatchee, WA. 130 pp.

Alexander, C.A.D. and K. D. Hyatt (eds). 2005. The Okanagan Fish-and-Water Management Tool (Ok-FWMT) Record of Design (v. 1.0.001). Prepared for the Canadian Okanagan Basin Technical Working Group (COBTWG) and Douglas County Public Utility District No. 1 (DCPUD), Draft report submitted to COBTWG and DCPUD, Sept. 2005.

Anonymous. 1973. Pacific Salmon population and habitat requirements. Task 162, Report for the Okanagan Study Committee, Canada/British Columbia Okanagan Basin Agreement. 44 p.

B.C. Lands, Forests and Water Resources. 1975. Osoyoos flood protection information. Issued by B.C. Water Resources Service.

Beacham, T. D. and C. B. Murray. 1990. Temperature, egg size, and development of embryos and alevins of five species of Pacific salmon: a comparative analysis. Trans. Am. Fish. Soc. 119(6): 927-945.

Brannon, E.L. 1987. Mechanisms stabilizing salmonid fry emergence timing, p. 120-124. In: H.D. Smith, L. Margolis, and C.C. Wood (Eds.). Sockeye salmon (*Oncorhynchus nerka*) population biology and future management. Can. Spec. Publ. Fish. Aquat. Sci. 96.

Bull, C.J. 1999. Fisheries habitat in the Okanagan River phase 2 - investigation of selected options. Prepared for Public Utility District No. 1 of Douglas County, WA.

Canada – British Columbia Okanagan Basin Agreement, 1974. Technical supplement I Water quantity in the Okanagan Basin. British Columbia Water Resources Service, Victoria.

Dobson, D. 2004. Hydrology and watershed management. Ch. 13 In M. A. Roed and J. D. Greenough (Eds.) Okanagan Geology, British Columbia. 2nd Edition, Kelowna Geology Committee. Sandhill Book Marketing, Kelowna, BC.

Glenfir Resources. 2006. Plan of Study for Renewal of the International Joint Commission's Osoyoos Lake Orders. 158p. Available at: http://www.ijc.org/rel/boards/osoyoos/final_pos_060811.pdf

Hourston, W. B., C. H. Clay, E. W. Burridge, F. C. Lucas, D. R. Johnson, H. T. Heg, W. R. McKinley, J. T. Barnaby, L. A. Fulton, and A. A. Gentry. 1954. The salmon problems associated with the proposed flood control project on the Okanagan River British Columbia, Canada. U. S. Fish and Wildlife Service, Washington State Dept. of Fisheries and Canada Dept. of Fisheries. 109 p.

Hyatt, K. D. and C. Bull. 2007. Fish and Water Management Tool project assessments: Record of management strategy and decisions for 2005. Can. Manusc. Rep. Fish. Aquat. Sci. 2808: *x* + 37 p.

Hyatt, K.D., C. Bull, and M.M. Stockwell. 2009. Okanagan Fish and Water Management Tool Project assessments: record of management strategy and decisions for 2005-2006 Fish-and-Water Year. Can. Manusc. Rep. Fish. Aquat. Sci. 2897: ix + 68 p.

Hyatt, K. D., E. Fast, M. Flynn, D. Machin, S. Matthews, and B. Symonds. 2001. Water management tools to increase production of Okanagan sockeye salmon. Fish-Water Management Proposal (June 21, 2001) submitted to Douglas County Public Utility Division No. 1, Wenatchee Washington. Canadian Okanagan Basin Technical Working Group Secretariat. 24 p.

Hyatt, K.D. and D.P. Rankin. 1999. A habitat based evaluation of Okanagan sockeye salmon objectives. PSARC Working Paper S99-18. Department of fisheries and Oceans, Pacific Science Advisory Review Committee, Pacific Biological Station, Nanaimo, B.C. 59 p. Available at: http://www.dfo-mpo.gc.ca/csas/Csas/publications/ResDocs-DocRech/1999/1999_191_e.htm

Hyatt, K.D., D.P. Rankin, H. Wright, M.M. Stockwell, E.V. Jensen, and D.J. McQueen. 2009. "Squeeze play" Responses of Okanagan River juvenile sockeye salmon to habitat changes driven by high epilimnetic temperature and low hypolimnetic oxygen in Osoyoos Lake, B.C. In preparation.

Hyatt, K.D. and M.M. Stockwell. 2007. Fish and Water Management Tool (FWMT) Project Assessments: Observations of Okanagan Sockeye Salmon (*Oncorhynchus nerka*) Egg Incubation Success, Fry Emergence Timing and Associated Environmental Conditions Between 1952-2006. Report to file: JSIDS-SRe 04-07. Salmon in Regional Ecosystems Program, Fisheries and Oceans Canada, Nanaimo, BC V9T 6N7. 42 p.

Hyatt, K.D. and M.M. Stockwell. 2003. Analysis of seasonal thermal regimes of selected aquatic habitats for salmonid populations of interest to the Okanagan Fish and Water Management Tools (FWMT) project. Can. Manuscr. Rep. Fish. Aquat. Sci. 2618: 27 + viii p.

Hyatt, K. D., M.M. Stockwell, H. Wright, K. Long, P. Askey, L. Weins, and K. Wodchyk. 2007. Okanagan Fish and Water Management Tools Project Assessments: Brood Year 2006 salmon (*Oncorhynchus nerka*) abundance and biological traits. Report to file: JSIDS-SRe 8-06. Salmon in Regional Ecosystems Program, Fisheries and Oceans Canada, Nanaimo, BC V9T 6N7. 26 p.

Okanagan Basin Implementation Board Canada (OBIB). 1982. Report on the Okanagan Basin Implementation Agreement (OBIA), September 1982.

Okanagan Basin Study Office. 1974. The Main Report of the Consultative Board, Including the Comprehensive Framework Plan. Prepared under the Canada-British Columbia Okanagan Basin Agreement, March 1974.

Stockwell, M.M. and K.D. Hyatt. 2003. A summary of Okanagan sockeye salmon (*Oncorhynchus nerka*) escapement survey observations by date and river segment from 1947 to 2001. Can. Data Rep. Fish. Aquat. Sci. 1106: 34p + data CD-ROM.

Summit Environmental Consultants Ltd. 2002. Observations and modeling of bed movement and potential redd scour in Okanagan River. Project report 635-13.01 prepared for the Okanagan Nation Alliance Fisheries Department, Westbank, B.C.

Table 1. Preferred flows for sockeye salmon in the Okanagan River at Oliver (Canada/British Columbia Report on the Okanagan Basin Agreement, 1973).

Sockeye Life History Stage	**Dates**	**Preferred Range (m^3/sec)**
Adult migration	Aug. 1 - Sept. 15	8.5 - 12.7
Spawning	Sept. 16 - Oct. 31	9.9 - 15.6
Incubation	Nov. 1 – Feb. 15	5.0 - 28.3 Incubation flows ≥ 50% spawning
Fry migration	Feb. 16 – Apr. 30	5.0 - 28.3

Table 2. Summary of key events or activities (by class and geographic location), risk factors or processes and indicators of relevance for users of the Okanagan Fish-and-Water Management Tools (FWMT) decision support system. The majority of indicators are generated within the FWMT system as model predictions (P) or measured observations (O) that are imported in near, real-time. Stars (❖) represent the primary indicators used for ongoing evaluation of changes in risk. A smaller set of supplemental indicators are generated and accessed by users from outside of the FWMT application (see text for further explanation).

Event or Activity	Risk Factor(s) or Process	Pressure, Status and Trend Indicator(s)	Source			
			Inside FWMT		Outside FWMT	
SOCIO- ECONOMIC			P	O	P	O
Okanagan Lake at Kelowna						
Surface elevation of Okanagan Lake	Okanagan Lake flooding and associated property damage. Okanagan Lake drought and storage deficit that impacts water access for irrigation and domestic water intakes.	❖ Okanagan daily to seasonal snow-pack values relative to average	X	X		
		❖ BC River Forecast Centre or user specified water supply forecast	X	X		
		o Regional snow-pack and/or rainfall events relative to average				X
		o Okanagan daily to monthly rainfall values relative to average	X	X		
		o Hourly to daily inflows from Mission Creek to Okanagan Lake	X	X		
		o Penticton Dam flow releases by hour	X	X		
		o Okanagan River discharge by hour	X	X		
		❖ Net inflows from tributaries relative to weekly or monthly average	X	X		
		❖ Okanagan L. daily to weekly lake level relative to seasonal targets	X	X		
Okanagan River at Penticton						
Discharge and water level in Penticton Channel	Flood induced damage to Penticton channel and/or flooding and water infiltration of riparian properties. Drought induced exposure of domestic and irrigation water intakes.	o Penticton Dam flow releases by hour	X	X		
		o Okanagan River discharge by hour	X	X		
		o Inflows from tributaries relative to weekly or monthly average	X	X		
		o Riparian landowner commentaries re: specific impacts on property				X
		o Flows in Penticton Channel within range for recreational “tubing”	X	X		
		❖ Okanagan R. daily discharge relative to seasonal targets	X	X		
Okanagan River at Oliver						
Discharge and water level in Oliver Channel	Flood induced damage to channel at Oliver and/or flooding and water infiltration of riparian properties. Drought induced exposure of	o Penticton Dam flow releases by hour	X	X		
		o Okanagan River discharge by hour	X	X		
		o Inflows from tributaries relative to weekly or monthly average	X	X		
		o Riparian landowner commentaries re: specific impacts on property				X
		❖ Okanagan R. daily discharge relative to seasonal targets	X	X		

Event or Activity	Risk Factor(s) or Process	Pressure, Status and Trend Indicator(s)	Source Inside FWMT P	Source Inside FWMT O	Source Outside FWMT P	Source Outside FWMT O
	domestic and SOLID irrigation intake at McIntyre Dam.					
ECOLOGICAL						
Kokanee Salmon in Okanagan Lake at Kelowna						
Kokanee spawning and incubation success on Okanagan Lake beaches (SE, NE, NW).	Risk of egg/alevin desiccation and loss due to spawn depth and subsequent lake level draw-down between time of egg deposition and fry emergence.	o No. of spawners by lake area (SE, NE, NW)				X
		o Spawn-depth	X			
		o Lake level	X	X		
		o Incubation temperature and accumulated thermal units (ATUs)	X	X		
		o Egg hatch and fry emergence date	X			
		❖ Magnitude of drawdown induced egg/alevin loss during incubation	X			
Sockeye Salmon in the Okanagan River at Oliver						
Adult salmon access to spawning area(s).	Migration blockage at vertical drop-structures due to high discharge. Access to spawning habitat reduced due to low discharge.	o No. of adult sockeye in riverine spawning grounds	X	X		
		o No. of adult sockeye in specific spawning areas and habitats	X			X
		❖ Discharge relative to migration & spawning compliance range	X	X		
Egg/alevin incubation and fry emergence success.	Flood or drought impacts on egg/alevin incubation and fry emergence success.	o Okanagan daily to seasonal snow-pack values relative to average	X	X		
		o Okanagan daily to monthly rainfall values relative to average	X	X		
		o Okanagan daily to weekly lake level relative to average	X	X		
		o Penticton Dam flow releases by hour	X	X		
		o Okanagan River discharge by hour	X	X		
		o Unregulated tributary discharge by hour	X	X		
		o Okanagan R. incubation temperature and ATUs	X	X		
		o Egg hatch dates	X			X
		❖ Scour and desiccation event-over-threshold drivers	X	X		
		❖ Fry emergence dates	X			X
		❖ Early summer fry recruitment index (no.spawner^{-1}) to Osoyoos L.	X			X

(continued)

Event or Activity	Risk Factor(s) or Process	Pressure, Status and Trend Indicator(s)	Source			
			Inside FWMT		Outside FWMT	
			P	O	P	O
ECOLOGICAL						
Sockeye Salmon in Osoyoos Lake						
Fry recruitment to Osoyoos Lake.	Flood or drought water-level or flow impacts on fry migration or emergence success.	❖ Discharge of Okanagan River at Oliver relative to emergence and migration compliance range	X	X		
		❖ Early summer fry recruitment index (fry.spawner $^{-1}$) to Osoyoos L.	X			X
Fry rearing in Osoyoos Lake.	Reduction or loss of preferred rearing habitat due to temperature-oxygen “squeeze” (*i.e.* excessive temperatures in surface waters and low oxygen in deeper waters).	o Calendar day surface temperature in Osoyoos L. exceeds 17°C	X	X		
		o Seasonal depth of 17°C isotherm in Osoyoos Lake	X			X
		o Seasonal depth of 4 mg.l-1 oxygen isoline in Osoyoos Lake	X			X
		o Seasonal depth distribution of sockeye fry	X			X
		o Average or cumulative discharge July-Sept at Oliver	X	X		
		❖ Volume of “optimal” water (VOW) for fry rearing	X			X
		❖ Early summer-to-fall survival of sockeye fry	X			X

Table 3. Members of the 2006 - 2007 FWMT Operational Team

Agency	Primary Representatives	Alternates
BC Ministry of Environment, Water Stewardship Division	• Des Anderson [a] • Don McKee [a]	• Ray Jubb
Fisheries and Oceans Canada	• Kim Hyatt	• Margot Stockwell
BC Ministry of Environment, Fish and Wildlife Science	• Andrew Wilson [b] • Paul Askey [b]	• Steve Mathews
Okanagan Nation Alliance	• Howie Wright	• Kari Long
ESSA Technologies Ltd.	• Clint Alexander (technical advisor)	• nil

(a) Staffing changes within the Water Stewardship Division (Okanagan Region) resulted in Des Anderson replacing Don McKee as Section Head, Public Safety and Protection in April 2007.

(b) Staffing changes within the BC Ministry of Environment (Okanagan Region) resulted in Paul Askey replacing Andrew Wilson as the MOE Fisheries representative in February 2007. Andrew continued to work with the FWMT Operational Team until June.

Table 4: Summary of Record of Management Strategy, Decisions and Outcomes for the 2006-2007 Fish-and-Water Management Cycle. Bullet numbers correspond to events highlighted in Figure 4.

Bullet/Date	**Comments**
(1) Oct – Dec 2006	**Event(s) and/or Outlook:** Low lake levels and limited precipitation throughout fall and early winter suggest a continuation of the 2006 summer/fall drought situation. Currently, Okanagan Lake is approximately 20cm below the recommended December benchmark of 341.9m. **Decision:** Reduce discharge for winter incubation period (Figure 4B, #1) but maintain flow at no less than 50% of fall spawning values (i.e. maintain discharge at Oliver of no less than 5.5 cms; Figure 4D, #1-4) to protect incubating sockeye eggs and to conserve water in Okanagan Lake where levels are below preferred winter benchmarks (Figure 4A, #1-3). **Outcome:** Releases at Penticton Dam are reduced from ~10 to 5cms to (a) protect sockeye eggs and shore spawning kokanee eggs from desiccation and, (b) refill Okanagan Lake to meet winter target levels.
Nov. 15, 2006	Several days of local, heavy rainfall in mid-November caused increases in unregulated tributary flows below Okanagan Falls and near Oliver. Releases at Penticton were reduced to ~3.0 cms as an additional water conservation measure; flows at Oliver remained consistent at 5.6 cms (Figure 4-B, C, D). Releases at Penticton were increased again as tributary inputs subsided.
(2) Nov. 28, 2006	**Outlook:** Very low flows (< 5cms) near Oliver combined with below freezing air temperatures (<-10°C) will likely initiate loss of some sockeye eggs from freezing. **Events:** An updated run of FWMT results in amber bar developing for sockeye eggs this week. Discharge readings at Oliver hydrometric station had dropped below recommended sockeye incubation rate of 5 cms (3.6 cms, Nov. 28) (Figure 4D, #2; Figure 7). Air temperatures have been sub-zero for nearly a week and are projected to remain that way for at least another week. Concern was expressed by DFO (Stockwell) and ONA Fisheries (Wright) regarding the high potential for freezing of sockeye eggs along gravel bars and in shallower locations due to low flows. **Outcome:** Water management (McKee) immediately identified the problem as icing on the WSC gauge at Oliver that had triggered false readings. WSC installed a heat lamp on the gauge to prevent future problems. True flows at Oliver were checked manually and found to be within the range recommended for safe sockeye egg incubation. Water temperatures were also checked and determined to be >3.0°C throughout the river (Okanagan Falls to Road 18).
(3) Jan. 2007	**Outlook:** The River Forecast Centre January 1st prediction is for somewhat above normal snow-pack conditions with an overall snow water index of 110% for the Okanagan-Kettle basin. The high elevation snow-pillow at Mission Creek is slightly below average (94%) while the low elevation snow-pillow at Brenda Mine is above average (112%). As the result of severe drought conditions through the summer and early fall of 2006, the level of Okanagan Lake remains 20cm below normal winter benchmarks (Figure 4A

	#3). Additionally, net inflows to the lake throughout November and December have remained nearly 40% below average due to the combined effects of below average precipitation and freezing conditions. **<u>Advice</u>:** Maintain water conservation in Okanagan Lake. **<u>Outcome</u>:** Penticton releases are kept to minimal discharges (mean = 5 cms) to avoid further drawdown of the lake, and to prevent desiccation of sockeye and kokanee eggs (Figure 4- A, B, D #3).
(4) Feb. 6-13, 2007	**<u>Outlook</u>:** The RFC forecast inflows to Okanagan Lake for the period Feb.1st to July 31st is 540 million m³ (± 146). This equates to approximately 103% of the all year average actual net inflows (base period 1974-2006). Snow-pack in the southern portion of the Okanagan is above normal (130%), but is near normal in the northern section (97% at Mission Creek). On average, approximately two thirds of the annual snow-pack has accumulated by February 1st and accordingly, a normal spring run-off is expected. **<u>Advice</u>:** Since late October, water management had been consistently keeping releases at Penticton Dam to minimum rates to prevent Okanagan L. level from dropping. By mid-February, the lake level was on a trajectory that would put it just slightly above the month end benchmark. Given the expectation of normal to somewhat above normal spring inflows, fisheries and water management (K. Hyatt, R. Jubb) recommended increased water releases in order to draw the lake down closer to the month-end average, target level of 341.7 m. **<u>Outcome</u>:** On Feb. 16th, water management began to incrementally increase releases at Penticton Dam through the remainder of February (Feb. 16th, 5 to 8 cms; Feb. 24th, 8 to 12.5 cms; Feb. 27th, 12.5 to 16.0 cms). The Feb. 25th lake target level of 341.7m was met (Figure 4- A, B #4).
(5) Mar.26, 2007	**<u>Teleconference Call</u>:** Paul Askey**,** Kim Hyatt, Deana Machin, Don McKee, Margot Stockwell, Andrew Wilson, Howie Wright, **<u>Event(s) and/or Outlook</u>:** Kim Hyatt circulated FWMT scenario 405 (Figure 10) by e-mail to Team members for discussion considerations. Weather conditions throughout February and into March remained unremarkable and total precipitation for this period was consistent with the all year average (1971-2000) for the southern Interior. As of March 1st, the snow water index reported for the Okanagan-Kettle region was essentially normal (101%). Snow conditions remained higher (113 - 134%) at the low elevation stations in the west Okanagan while in the north, high elevation stations were near normal (Mission Creek 99%; Silver Star 105%). Snow-packs at this point are similar to those at the same time in 2006 (Figure 8). The RFC forecast inflows to Okanagan Lake for the period March 1 to July 31 is 510 kdam^3 (± 114). This estimate is well within the all year average (503 kdam^3± 218). **<u>Discussion</u>:** Recent net weekly inflows to Okanagan L. show a slight increase associated with March 23-25th precipitation events. Current releases are roughly 15 cms at Penticton and 17.5 cms at Oliver reflecting additional unregulated tributary inputs. As with last year, there is still some potential for late winter/early spring increase to snow-pack, thus it may be advisable to increase releases and draw Okanagan lake down further to accommodate additional inflows. Water management (McKee) would like to increase flows

	at Penticton (to 18-20 cms) to draw lake down to the April 1st benchmark of 341.55m (currently at 341.66m) (Figure 4A, #5). However, he expressed concern that drawdown of this magnitude triggers an amber warning in the FWMT kokanee development bar (Figure 10A). DFO (Stockwell) noted that field observations of sockeye hatch appear to be approximately 3-4 weeks ahead of FWMT predictions. Emergence is likely to be about 2 weeks ahead of what the model is predicting. **Advice:** DFO (Hyatt) recommends increasing flows to 20-24 cms to bring lake level down closer to winter benchmarks and to avoid potential "panic releases" later in the spring and thus, undue scour of sockeye alevins. Protection of kokanee by continued maintenance of low releases will place a higher proportion of sockeye at risk of losses from scour in May. Consequently, increases in spill need to begin soon to balance risks between the two species as well as to avoid later flood risk. **Decisions:** Releases at Penticton Dam will be increased (maximum of 24 cms at Oliver) immediately. Provincial Fisheries (Wilson) are agreeable to this as the majority of kokanee are considered to be safe at this date and any impacts to them by further drawdown are minimal (Figure 4A, #5). **Outcomes:** Water management increased releases at Penticton Dam to ~21 cms as of March 29 (Figure 4B, #5).
(6) Apr. 10, 2007	**Teleconference Call:** Des Anderson, Paul Askey, Kim Hyatt, Don McKee, Margot Stockwell, Howie Wright **Event(s) and/or Outlook:** Kim Hyatt posted scenario 408 (Figure 19) to the FWMT online Narrative section for discussion considerations amongst Team members. The April 1 to July 31 RFC forecast of 480 kdam³ (± 101 kdam³) falls within the all year average. The overall Okanagan-Kettle snow-water index is 94% of normal. Snow-pack at Mission Creek pillow (high elevation) remains average while Brenda Mine (low elevation) is slightly above average at the beginning of the month. A high increase in air temperatures this week initiated rapid snow melt in the very low elevation basins (e.g. Vaseux) resulting in substantial increases to unregulated tributary flows (Figure 4C & D, #6). In response to the rapid increase in these flows, Water Management reduced releases at Penticton Dam April 9 (20 cms to 16cms) to avert scour inducing flows at Oliver (Figure 4B, #6). FWMT identifies 100% emergence for Okanagan lakeshore kokanee (12-Apr-07) without any undue loss due to premature reductions in Okanagan Lake levels, that is, the "kokanee-friendly" lake level objective was met for this portion of the 2006-2007 fish-and-water management cycle (Figure 4A). Data collected from field sampling suggests that 100% sockeye emergence is likely to be approximately 2 weeks earlier than predicted by the model. At this point in time, flood and scour risk to sockeye alevins remains low. **Discussion:** The regional snow-pack is very close to the all year average and barring any unforeseen acts by Mother Nature (early high air temperatures resulting in rapid, early snow melt or late spring snow accumulations at higher elevations as in 2006), sockeye will safely complete emergence and the likelihood of any flooding remains low.

	<u>Advice</u>: Continue with current releases until more information is available (May RFC forecast, seasonal changes to tributary flows, etc.).
Apr. 29, 2007	**<u>Outlook Update</u>:** (1) Snow-packs at Mission Ck and Brenda Mine remain close to the seasonally adjusted, all-year average. (2) Almost 50% of the lower elevation snow-pack (e.g. 1400m Brenda Mine) has dissipated; higher elevation snow (e.g. 1800 m Mission Ck) has experienced only modest loss to date. (3) Net tributary inputs in late March to mid April were above the all-year average but cooler weather in late April has slowed inputs to sub-average. (4) Okanagan Lake has been rising more slowly than expected ("Average" Scenario 416, Figure 11) but a cool late April and lower than average inputs from unregulated tributaries downstream has allowed continuation of a spill of about 18 cms at Penticton (Figure 11D) without exceeding 23 cms at Oliver so scour of sockeye redds is not currently an issue. (5) Sockeye fry emergence is well underway, although there is as yet no clear sign that peak emergence has passed. Emergence this year appears to be following a broadly "dome shaped" rather than more knife edged pattern. Water managers will be kept appraised of sockeye emergence progress.
May 7, 2007	**<u>Outlook Update</u>:** (1) Lower elevation (1460m) snow-pack at Brenda Mine is following the all-year average closely - about 65% of the snow-pack has dissipated. (2) The May 1 to July 31 RFC forecast of 400 kdam³ (± 150 kdam³) falls close to the all year average (383 kdam³). (3) The higher elevation (1780m) snow-pack at Mission Ck is close to average but is exhibiting a delayed seasonal melt such that weekly net inflows to Okanagan Lake have been sub-average for past three weeks (i.e. weeks ending April 22, April 29, and May 6th; Figure 9B). (4) No significant rainfall is expected for the next 5 days but tributary inputs should increase greatly as warmer air temperatures promote melt. (5) Current water releases at Penticton Dam are 18.8 cms and 24-25 cms at Oliver reflecting increased tributary inputs from snow melt. (6) In spite of later emergence predicted under FWMT-ATU model, field sampling revealed that sockeye fry emergence peaked around April 24 and had dramatically declined by May 3 (Figure 12A). The discrepancy between predicted and observed fry timing is due to the fixed ATU model within FWMT. (6) Although FWMT suggests red hazard on the sockeye bar at early May (See Scenario 421, Figure 20), spill >29 cms at Oliver produces low risk of scour to sockeye fry as emergence is nearly complete.
(7) May 18, 2007	**<u>Event(s) and/or Outlook</u>:** Melt and runoff of low elevation (<1500m) snow-pack at Brenda Mine and other low level locations is complete as of May 18th (Figure 8B). However, resulting water yield to Okanagan Lake is much lower than expected. Higher elevation (>1700 m) snow-pack at Mission Creek has now dropped below the all-year, seasonal average (Figure 8A). Net tributary inflows have remained sub-average for the past five weeks (Figure 9B) and attained only 66% of the all-year average for the week ending May 20th, suggesting the seasonal hydrograph may decline earlier than average given continued sub-average precipitation during May. Cumulative precipitation to May 19th measures about 15mm relative to an all-year average of 39 mm for the month of May (Figure 6). Okanagan Lake level (currently 342.00 m) has

	been increasing steadily at 1.4 cm per day but at this rate, will require 38 days to refill to the preferred level of 342.54 m by June 28th (Figure 4A, #7). Finally, both the 5 and 14 day Environment Canada outlook suggests that there is little prospect for supplemental precipitation. Field surveys confirm that sockeye fry emergence was complete by May 11 (Figure 12). The "sockeye-friendly" river flow objectives were met for this portion of the 2006-2007 fish-and-water management cycle (Figure 4D egg and alevin hazard bars). **Issue:** Evidence of declining snow-pack and sub-average water yield raised concerns among the operations group members that current rates of spill of 15 cms at the Penticton Dam (Figure 13B) will not allow Okanagan Lake to reach the preferred 342.54 m level benchmark by June 24th (Figure 13A). **Evidence is building towards the onset of early season drought conditions in the Okanagan**. **Advice:** Consensus of FWMT team (McKee, Hyatt, Wright, Stockwell) during a May 16th meeting in Penticton was that annual flows from snowmelt and May precipitation in the Okanagan would fall between the all-year average and one standard deviation below the all-year average. **Increased storage of water appears prudent in anticipation of a dry spring and early summer.** **Decisions:** Spill rates at the Penticton Dam were decreased from 15 cms to 11-12 cms on May 17th to increase rate of Okanagan Lake refill (Figure 4B, #7). **Outcome**: To be reviewed again in late May.
(8) May 24-30	**Issue:** ***Dryer than expected conditions appear imminent for summer 2007 in the Okanagan!*** The "average" water yield predicted from the May 1st RFC forecast appears biased high (i.e. the May RFC forecast of 400 kdam³ (range 250-550) is more likely to come in at 325 kdam³ at the lower end of the predicted range). ***In the absence of above-average precipitation events over the next three weeks, Okanagan Lake will not achieve the preferred 342.52 m level benchmark by June 24th.*** **Event(s) and/or Outlook:** Melt and runoff of snow-pack throughout the Okanagan Valley is nearly complete as of May 30th (Figure 8). Water yield to Okanagan Lake is much lower than expected and continues to slow even with high air temperatures and accelerated melting rates of remaining snow this week. Higher elevation (>1700 m) snow-pack at Mission Creek has dropped to less than 30% of the seasonal average. Current projections suggest the remainder of high elevation melt will occur no later than June 15th. Net tributary inflows have been sub-average for the past six weeks (Figure 9B) with the sharpest drop in the most recent week ending May 27th (see tributary inflow trends in Figure 4 C & D, #8) producing only 41% of the all-year average water yield. Tributary inflows are declining with Mission Ck inflow at less than 15cms which is less than 50% of the flow values observed at this date last year (i.e. 30-40 cms). Cumulative precipitation to May 30th remains at roughly 15 mm relative to an all-year average for May of 39 mm. Both the 5 and 14 day Environment Canada outlooks suggest little prospect for supplemental precipitation. Okanagan Lake level (at 342.08 m) is

	currently increasing at about 0.67 cm per day suggesting it may reach 342.20 m or **32 cm below the preferred mid-June lake level** (Figure 4A, #8). FWMT "Graphs Low" Scenario-432 (Figure 13) with water supplies at 1 standard deviation below average *is still too optimistic*. Scenario-432 anticipates low enough water supplies that agricultural and domestic water intakes may be affected and a severe temperature-oxygen "squeeze" will occur and place Osoyoos sockeye at risk of loss between late Aug and mid-October (Figure 13D). **<u>Advice</u>:** We should probably reset the water yield estimates in FWMT lower than the May RFC estimate of 400 kdam³ and then run additional FWMT Scenarios. However, even without this, ***aggressive water storage and conservation appears warranted*** until the water supply situation improves. **<u>Decisions</u>:** Awaiting additional comment from water management. **<u>Outcome</u>:** Releases at Penticton Dam reduced to ~6 cms by the end of May; discharge at Oliver down to ~6 cms also (from 10.6 on May 24th).
May 26 - June 3	The conspicuous drop in unregulated tributary input near June 2 (Figure 4C & D, #8) may be attributed to high water extraction for domestic irrigation purposes. Typically, the May holiday weekend sees higher than normal irrigation demand (Brian Symonds, pers. comm.). Additionally, this year the air temperatures spiked to over 30°C for the long weekend and the following week.
(9) June 18, 2007	**<u>Issue</u>:** Dryer than expected conditions have persisted through much of June! The "average" water yield of 400 kdam³ (range 250-550) predicted from the May 1st RFC forecast appears more likely to come in at the lower end of the predicted range (i.e. current projections suggest a value closer to 350 kdam³). Okanagan Lake is very unlikely to achieve the preferred 342.52 m level benchmark by June 24th (Figure 4A, #9). Moreover, in the absence of above-average precipitation events over the next three weeks, ***Okanagan Lake may even fail to reach the preferred benchmark level of 342.30 m by July 29th. Satisfaction of late summer water demands to meet both irrigation and fisheries needs poses a challenge***. **<u>Event(s) and/or Outlook</u>:** Snowmelt has been complete for at least two weeks. Net tributary inflows have been sub-average for the past nine weeks (i.e. from the week ending April 22nd to the week ending June 17th). Although two significant precipitation events of greater than 10 mm occurred in June and promoted increases of roughly 6 cm in Okanagan Lake level, the latter are likely to be short-lived in the absence of continued above average precipitation in late June through July. Average net inflows from tributaries (Mission Ck, Inkaneep and Vaseux) are currently only one-half to one-third of the values observed for the week ending June 17th in 2006 and suggest that negative net inputs may occur earlier this year than the third week of July all-year average. If reduced water supply precludes attainment of the preferred 342.30 m level for Okanagan Lake by July 29th, satisfaction of late summer water demands to meet irrigation and fisheries needs will pose a challenge. In particular, if a temperature-oxygen squeeze develops to threaten sockeye fry rearing in Osoyoos Lake, there may be little surplus water to permit a "pulsed flow" release to mitigate such conditions. Similarly, refill to Sept. benchmarks for Okanagan Lake and provision of adequate water for sockeye

June 29, 2007	spawners could become an issue. **<u>Advice</u>:** As of this writing, aggressive water storage and conservation appears warranted until the water supply situation improves. Opportunities to create a water supply "buffer" in June-July to allow pulsed flow in August-September are encouraged from a fisheries perspective. **<u>Decisions</u>:** E-mail of June 29th from Des Anderson (BC MoE) to the FWMT Operations group stated that "Conservation flows have been implemented (under the British Columbia / Washington State Cooperative Plan) while meeting current agricultural intake objectives. This will maximize storage in Okanagan Lake for both late summer irrigation demand and fisheries pulsed flow in August-September." **<u>Outcome</u>:** Rainfall events in late June and timely steps to conserve water helped move Okanagan Lake levels to 342.26 m as of July 1st - just 4 cm short of the preferred July 28th benchmark of 342.30 m. Penticton Dam releases increased (to ~8.6 cms) to meet downstream intake needs (Figure 4 B, C, & D, #9).
(10) July 12, 2007	**<u>Issue</u>:** Extremely dry conditions persist throughout the Okanagan Valley. The area is currently experiencing "record breaking" high temperatures and consequently, increasingly high demands for water. Okanagan Lake will likely fail to reach the preferred July 29th benchmark level of 342.30 m. Escalating drought conditions pose a serious threat to sockeye smolt survival in Osoyoos Lake during the late summer-early fall of this year as there may no surplus water to initiate a "pulsed flow" release to mitigate T/O_2 squeeze conditions. **<u>Event(s) and/or Outlook</u>:** Total spring run-off entering Okanagan Lake reached approximately 66% of the all year average and as a result, the lake level fell 25cm short of the preferred June 24th benchmark of 342.54 cm. However, total June precipitation exceeded 78mm (all year average = 41mm) and contributed an additional 2 cm to the lake by the end of June such that it appeared the July 29th benchmark of 342.30 might be reached. But, precipitation influence on unregulated tributary inputs to Okanagan River below Penticton was minimal and net discharge near Okanagan Falls and Oliver began to decrease substantially by late June. Water managers were compelled to begin increasing releases (to ~8.5 cms from ~4.0 at Penticton) (Figure 4B, #10) to meet agricultural intake objectives at the lower river locations. By the week of July 8, the Okanagan was experiencing extremely high temperatures (>35°C). Water managers again increased releases (to 13 cms) at Penticton to compensate for negative inflows of downstream, unregulated tributaries while continuing to meet agricultural and domestic intake requirements. Weather conditions contributed to additional lake level decreases of approximately 0.75 – 1.0 cm/day through evaporative loss. Okanagan Lake peaked at a level of 342.29 m on July 4 and began declining again during the week of July 8. If current weather conditions continue, the July 29 benchmark level will not be reached. Escalating drought conditions pose a serious threat to sockeye smolt survival in Osoyoos Lake during the late summer – early fall. Current extreme hot, dry weather conditions and necessary low water releases suggest that there may be an early onset of

	the temperature/O_2 “squeeze” this year. Furthermore, decreasing Okanagan Lake levels (water supply) indicate there is unlikely to be surplus water available for “pulsing” to facilitate an increase in usable rearing volume for the smolts. Similarly, refill to September benchmarks for Okanagan Lake is becoming increasingly unlikely and provision of adequate water flows for sockeye spawners in the fall could become an issue. **<u>Advice</u>:** Aggressive water storage and conservation continues to be crucial. **<u>Decisions</u>:** Water managers maintain conservation flows – increasing releases as necessary to meet agricultural and domestic intake requirements (Figure 4 B, C, D, #10). **<u>Outcome</u>:** Another summer storm system entered the Okanagan Valley during the week of July 17th. Cooler weather, the addition of 33 mm of precipitation to the area, and seasonal water conservation, helped to alleviate immediate drought concerns. By July 29, Okanagan Lake reached a level of 342.27m, just slightly short of the preferred benchmark level of 342.30m (Figure 4A, #10). Low scenario 430 (continuation of drought conditions; Figure 14) predicts that there may be adequate water available for a 2 week, 30 cms “pulse” (Figure 14B) to Osoyoos Lake during the last week of August – first week of September. All benchmarks throughout September would be reached and sufficient flows would be available to sockeye spawners in the fall. To date, there are no extenuating circumstances requiring water managers to sustain a high lake level (e.g. no concerns re: floating pontoons for new Kelowna bridge as last year) and thus preventing additional releases at this time.
(11) Aug. 20, 2007	**<u>Teleconference Call</u>:** Kim Hyatt, Des Anderson, Ray Jubb, Steve Matthews (BC MoE) **<u>Issue</u>:** Summer drought and a prolonged interval of low flows into Osoyoos L. preclude achieving cumulative July-Sept average inputs of 145-160 million cubic meters of water regarded as the threshold to avoid development of temperature-oxygen “squeeze” conditions that reduce effective rearing volumes for sockeye in Osoyoos L. (see Osoyoos L. rearing-habitat performance indicator panel of Scenario-452 (Figure 16D) saved under the FWMT Narrative tab). **<u>Event(s) and/or Outlook</u>:** Several surveys of temperature and oxygen conditions in Osoyoos L. have been completed since May to follow the development of any significant temperature-oxygen squeeze that might impact juvenile salmon rearing habitat. A survey on August 13, 2007 indicates the17°C isopleth currently restricts juvenile sockeye to depths of 15m or greater in Osoyoos L. The 4 ppm oxygen concentration that normally restricts sockeye from occupying deeper waters is not in evidence at this date so all waters of 15 m or greater may be occupied by sockeye (Figure 17). Our current expectation is that reductions in rearing habitat are likely to materialize by mid-September. Some evidence suggests a pulsed flow of water coincident with the onset of temperature-oxygen “squeeze” conditions may reduce the severity of the event by flushing organic matter out of the epilimnion of Osoyoos L. thus reducing hypolimnetic loading and its associated biological oxygen demand.

	In an Aug. 20th teleconference, members (Anderson, Matthews, Jubb, Hyatt) of the fish-and-water management operations team discussed current water supply and fish habitat conditions. Consensus was achieved on the following points: (1) sufficient water is available in Okanagan L. to provide a pulsed flow event by releasing 25 cms at the Penticton Dam between Sept. 10th and Sept. 24th, (2) reductions in Okanagan L. level associated with increased releases will still permit regulation of lake levels at or near the preferred elevation for spawning kokanee by early October, (3) effects of elevated water releases on temperature-oxygen conditions in Osoyoos L. will be assessed through direct observations of temp-O2 conditions immediately before and then after any "pulsed release" of water, (4) the Sept 10-24th interval of increased flows at Oliver will not interfere with adult sockeye migration or maintenance of Okanagan Basin Agreement (OBA) flows for spawning if sockeye timing follows recent year values (i.e. recruitment and spawning after the end of Sept.) and, (5) if sockeye recruitment and initiation of spawning occur prior to Sept. 24th, water releases will default immediately to flows specified under the OBA. **Advice:** FWMT Scenario-452 (Figure 16A) suggests there is sufficient water for 2 weeks of 25 cms, pulsed flows (Figure 16B) to relieve temperature-oxygen squeeze conditions. Pulsed flows may have the greatest value if timed to coincide with the point at which the 4 ppm O_2 isopleth reaches a depth between 20-25 m. Our current expectation is that this will occur by mid-Sept. **Decisions:** Operations group discussions suggest a pulsed flow trial is both feasible and desirable. The consensus of the operations group supports a decision to increase releases of water at the Penticton Dam to 25 cms starting Sept 10th and ending Sept 24th after which OBA flows (Table 1) for sockeye recruitment and spawning will be maintained (see Scenario-452 attached; Figure 16 B and C). Additional information on the status of adult sockeye in the Okanagan R. and temperature-oxygen conditions in Osoyoos L. will be provided prior to Sept. 10th to confirm that prevailing conditions still warrant the proposed flow increase. **Outcome:** See September 25th.
(12) Sept.25, 2007	**Issue:** Summer drought and a prolonged interval of low flows into Osoyoos L. precluded achieving cumulative July-Sept average inputs of 145-160 million cubic meters of water. The latter is regarded as the threshold to avoid development of temperature-oxygen "squeeze" conditions that reduce effective rearing volumes for sockeye in Osoyoos Lake. **Event(s) and/or Outlook:** Several surveys of temperature and oxygen conditions in Osoyoos L. have been completed since May to follow the development of any significant temp-O2 squeeze that might impact juvenile salmon rearing habitat. Surveys on Aug. 13th and again on Sept. 4th indicated a rapid ascent of the 4 ppm oxygen isopleth to 15 m such that it converged with the17 degree isopleth thus reducing the useable water volume for juvenile sockeye in Osoyoos Lake to a value near zero (Figure 17). Confirmation of the development of a late summer temperature-oxygen "squeeze" supports an earlier recommendation (August 20th) of the Operations Team to conduct a pulsed-release of water from Penticton Dam

	given evidence that increased flows may have a beneficial influence on oxygen levels in the hypolimnion of Osoyoos Lake. **Advice:** Increase releases of water at the Penticton Dam to 25 cms starting Sept 10th and ending Sept 24th after which OBA flows for sockeye recruitment and spawning will be maintained. **Decision:** During the Sept.10-24th interval BC Water Stewardship Division personnel increased releases at the Penticton Dam from 12 to 25 cms to provide a pulsed-flow event in Osoyoos Lake as per the Aug. 20th agreement among the Fish-and-Water Operations Team members (Figure 4 B, C, & D, #12) **Outcomes:** Epilimnial cooling and a retreat of the 4 ppm oxygen isopleth to a depth of about 18 m accompanied the pulsed flow event such that the useable water volume for juvenile sockeye expanded significantly between Sept. 4th and 18th (Figure 17). The severity and duration of the oxygen depletion event during 2007 were of a lesser magnitude than observed during 2006 *(red lines identify the extent of the severe temperature-oxygen "squeeze" that developed in 2006*). Our current expectation is that further reductions in useable water volume for juvenile sockeye in Osoyoos Lake are unlikely to occur during the remainder of 2007.

Table 5. Inflow estimates (Kdam³) to Okanagan Lake entered into the Fish-Water-Management-Tool System for water year 2006-2007. Estimates are provided by personnel from the BC River Forecast Centre at the beginning of each month (Feb to May). The historical average is based on 32 years (1974 - 2006) of data.

Forecast Period (2007)	Uncertainty Type	RFC Estimate (Kdam³)	Historical Average (Kdam³)
Feb 1 - Jul 31	Mean -1StDev	394	296
Feb 1 - Jul 31	**Mean**	**540**	**521**
Feb 1 - Jul 31	Mean +1StDev	686	746
Mar 1 - Jul 31	Mean -1StDev	403	285
Mar 1 - Jul 31	**Mean**	**510**	**503**
Mar 1 - Jul 31	Mean +1StDev	617	721
Apr 1 - Jul 31	Mean -1StDev	379	265
Apr 1 - Jul 31	**Mean**	**480**	**473**
Apr 1 - Jul 31	Mean +1StDev	581	681
May 1 - Jul 31	Mean -1StDev	250	197
May 1 - Jul 31	**Mean**	**400**	**383**
May 1 - Jul 31	Mean +1StDev	550	569

Table 6. Variation in time to 100% sockeye hatch and emergence for Brood Year 2006 as determined by multiple methods. Note that cohort 2 dates are representative of peak hatch and emergence dates for which field observations may be determined more reliably than for 100% hatch and emergence dates represented by cohort 3.

A.

Cohort	Estimated Spawn Date	FWMT Predictions: 100% Hatch Date	FWMT Predictions: ATU's	Belehrádek Method: 100% Hatch Date	Belehrádek Method: ATU's	Field Sampling (100% Hatch)
1	15-Oct-06	10-Mar-07	595	13-Feb-07	549	
2	22-Oct-06	4-Apr-07	595	11-Mar-07	501	
3	29-Oct-06	17-Apr-07	595	29-Mar-07	484	7-Mar-07 [a]

B.

Cohort	Estimated Spawn Date	FWMT Predictions: 100% Emergence Date	FWMT Predictions: ATU's	Belehrádek Method: 100% Emergence Date	Belehrádek Method: ATU's	Field Sampling (100% Emergence)
1	15-Oct-06	1-May-07	882	1- May-07	879	
2	22-Oct-06	11-May-07	883	10-May-07	881	
3	29-Oct-06	17-May-07	888	17-May-07	883	11-May-07 [b]

[a] <5 eggs per redd observed during hydraulic sampling of redds.

[b] >99% of cumulative catch from fyke net sampling (Figure 12b).

Table 7. Some problems encountered during Water Year 2006 - 2007 and recommendations for avoiding similar problems in the future.

Problems Encountered	Recommendations
• FWMT is offline, or • FWMT runs get "hung up" and will not advance to the current date (commonly due to a breakdown in communication between real-time hydrometric gauges and WSC or between the WSC and FWMT servers). • There can be a lag (up to a few days) before the above situation is corrected which could be detrimental in times of rapidly changing climate/water conditions.	• Prepare list of technical support contacts (WSC and FWMT) who can identify the source of problems / restore service. • Establish a reporting protocol for support services (priority of contacts); identify appropriate response times to correct miscellaneous problems. • WSC could provide a newsgroup for COBTWG that informs FWMT users when there are scheduled or unexpected communications breaks.
• False values from real-time hydrometric gauges trigger unwarranted hazard warnings (e.g. icing on gauge yields false discharge reports).	• Contact WSC (as noted above) to determine if there are actual problems with the gauges. • Contact local WS personnel who can physically check gauges and determine the problem. • Note: The retrofit of the Oliver gauge with heating coils to prevent freeze-up causes false water temperature readings that generate unreliable ATU estimates that drive egg hatch and fry emergence predictions in the sockeye sub-model.
• Output display of the Osoyoos Lake temperature-oxygen "squeeze" hazard indicator graph is difficult to understand for many FWMT users. • A red hazard indicator on the "rearing sockeye fry" bar can not be changed after a specific date even if physical parameters which will alleviate the squeeze improve.	• Modify temperature-oxygen squeeze algorithm within FWMT to predict/illustrate the onset and duration of the temperature-O_2 squeeze. • Change graphic display to reflect changing depths of 17°C and 4ppm O_2 isopleths (visual display of remaining habitable rearing volume) over time. Degree of convergence of isopleths will depict severity of squeeze (see Discussion).
• Difficult for FWMT users to distinguish between actual and "predicted" unregulated tributary flow lines on output graphs (Okanagan R. at Okanagan Falls and Okanagan R. at Oliver).	• Clarify graphic display such that actual and predicted flow lines are represented by different colours.

Problems Encountered	Recommendations
• Okanagan Lake summer target levels are not high enough to represent the need for additional water storage required for mitigation of the Osoyoos Lake temperature-oxygen squeeze through pulsed water releases.	• Current summer targets are operational targets for water stewardship to accommodate lake level preferences for kokanee spawners and spill for adult sockeye migration and spawning. Summer target levels in FWMT could be set slightly higher to promote additional water storage required for late summer pulse releases.
• Observed and predicted (FWMT model values) dates of 100% hatch and emergence can vary up to several weeks. This is due to fixed ATU method that FWMT uses within the model.	• Incorporate Belehrádek equation into FWMT (see Discussion).
• 100% hatch and emergence dates on the sockeye hazard bars do not correspond to 100% dates in ATU spreadsheet output (10-12 days difference in 2007; Table 6). This creates some confusion as users more often rely on the graphic output than spreadsheet values.	• Amend internal coding to reflect common dates.
• New users would like to be able to complete "practise" runs to familiarize themselves with, and gain confidence in using the model.	• Reinstate access to retroactive (historic) water years for training purposes. • Provide training workshop(s) for inexperienced users.
• Scenarios for discussion usually fall to one person.	• Designate OT members to update/run scenarios for discussion.
• Some agencies are not represented at annual meetings/teleconference calls.	• Make sure different agencies have alternate representatives that can be present.
• Hydraulic sampling of redds is not yielding any additional information re: hatch timing for comparison with FWMT predictions (getting extremely high variance on hatch timing due to inconsistent methods).	• Drop hydraulic sampling and reallocate funds to increase field sampling dates for fry emergence. Accurate knowledge of 100% emergence date is especially critical in high freshet years.

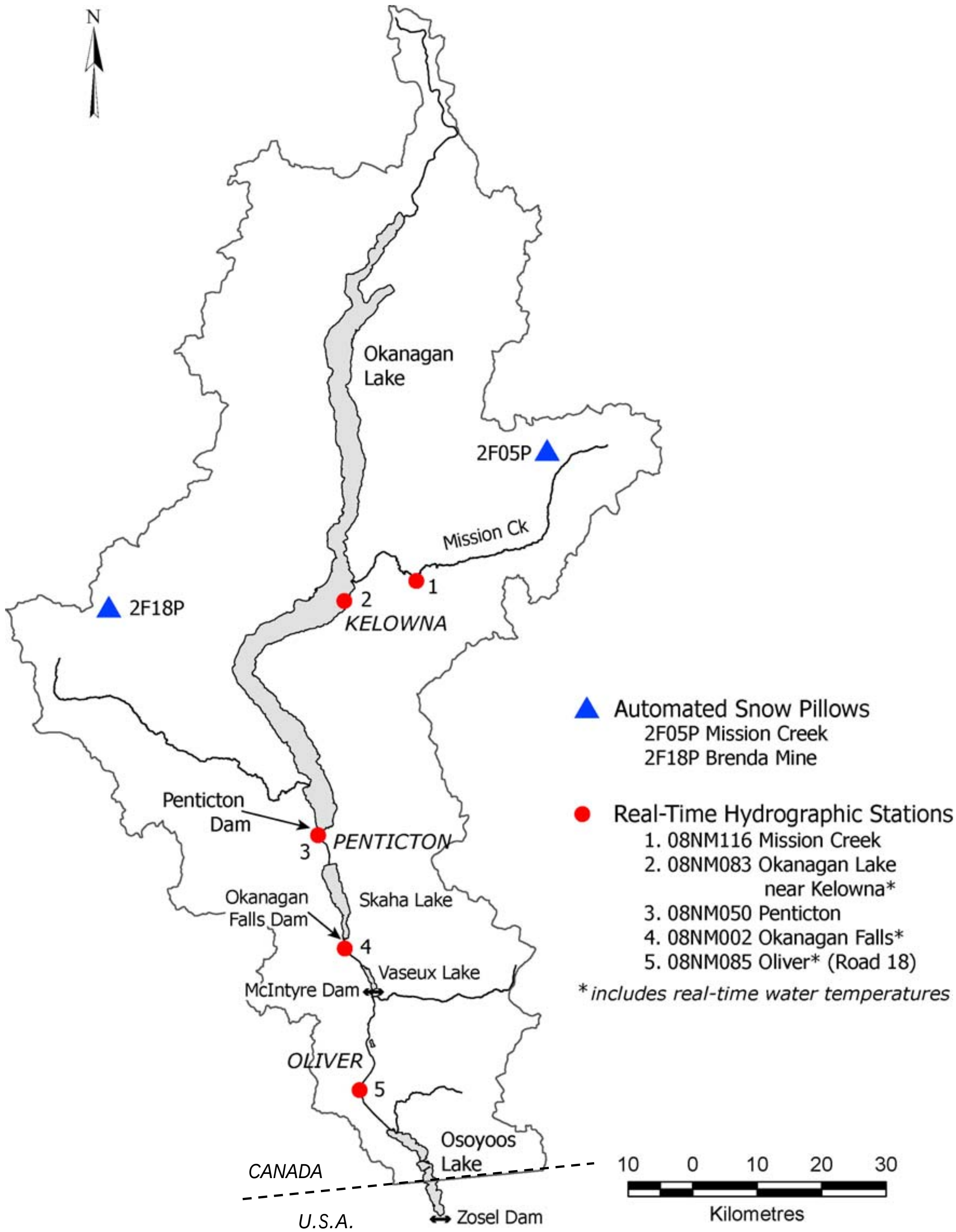


Figure 1. Map of major lakes, dam sites (Penticton, Okanagan Falls, McIntyre, Zosel), monitoring stations (snow-pack, water supply and temperature) and towns within British Columbia's Okanagan Basin.

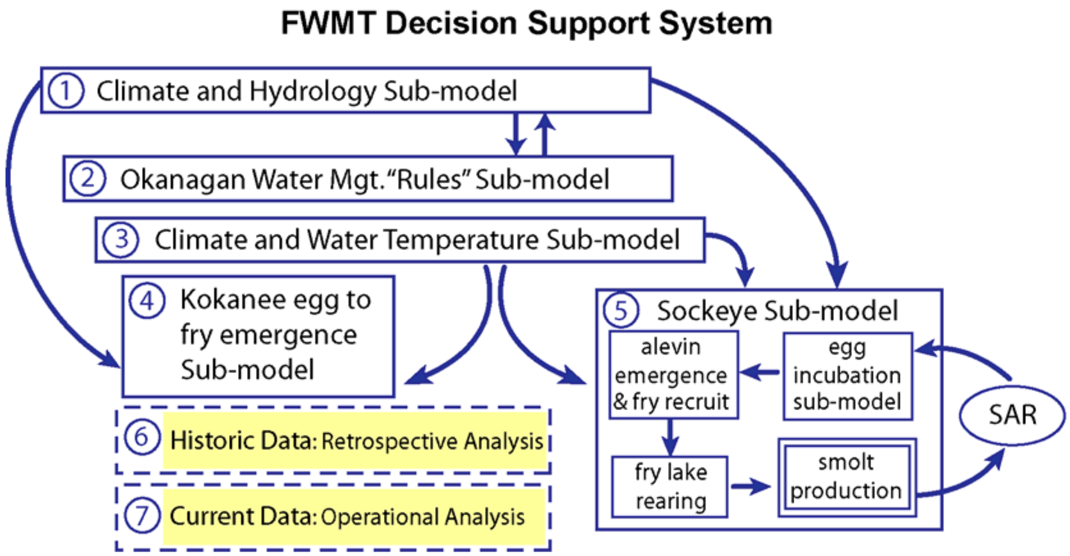


Figure 2. FWMT is a coupled-set of 4 biophysical models of key relationships among climate, fish and water that interact with a fifth, water-management rules model used to predict consequences of water management decisions for fish and other water users. FWMT software allows system users to explore water management decision impacts in near "real-time" (current-mode), historic intervals (retrospective-mode) or future intervals (prospective-mode) given data on water supplies, climate and fish population state(s).

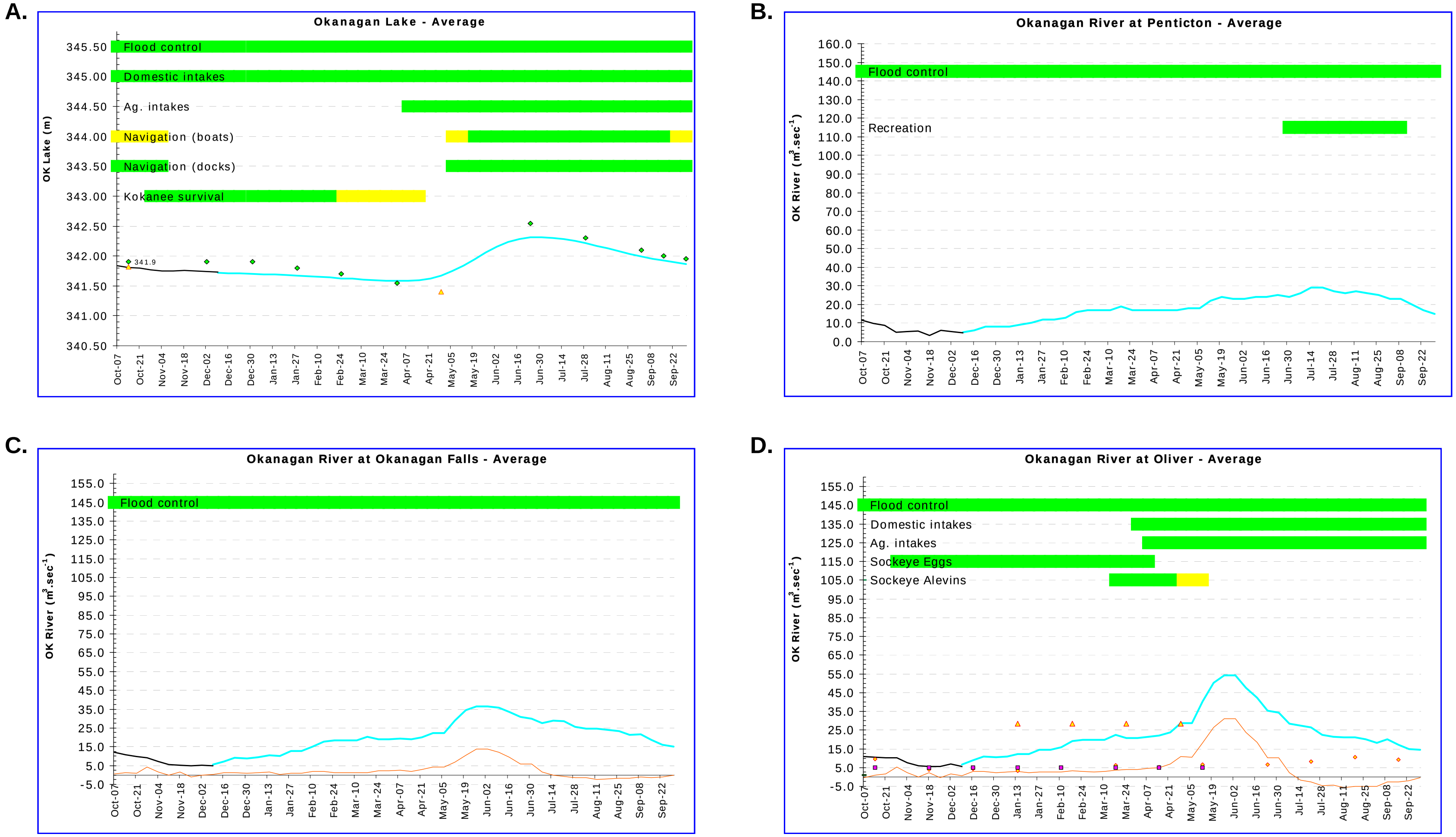
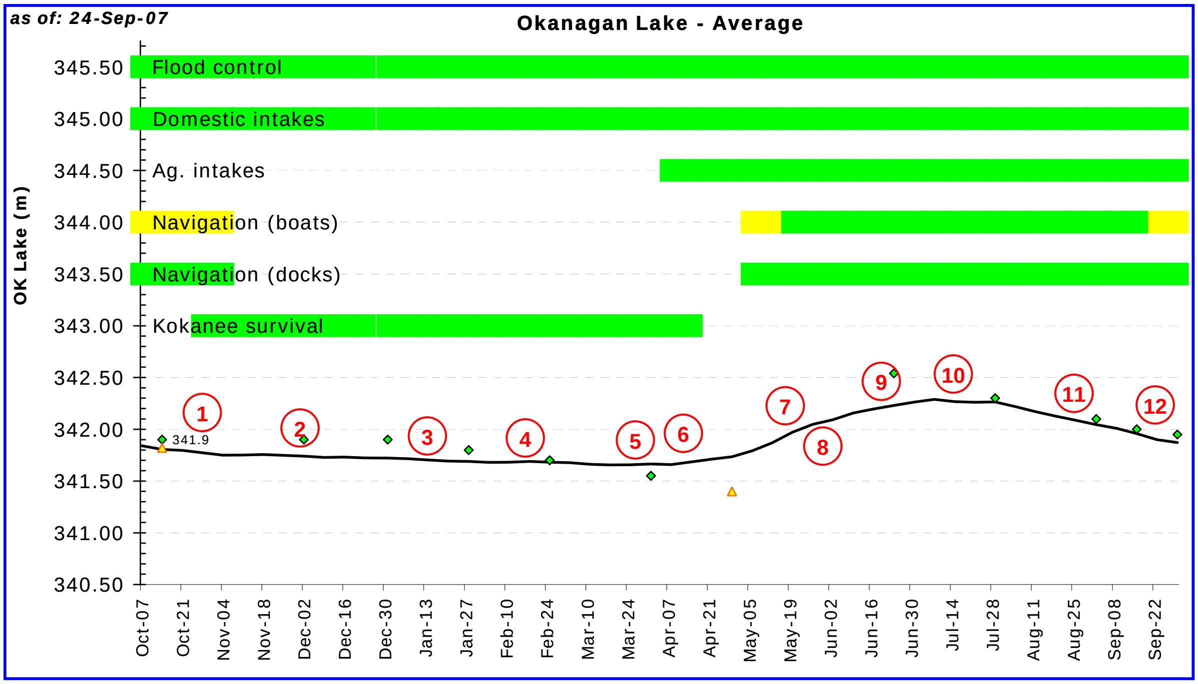


Figure 3. Results of FWMT Scenario 389 run by Margot Stockwell on December 6, 2006. Solid black lines represent observed lake level elevations or river discharge to date. Blue lines are predicted lake elevations and flows by location, given (a) an RFC or user specified annual inflow forecast and (b) a user specified pattern of water storage or release at the Penticton Dam. Green diamonds (Panel A) are preferred seasonal targets for Okanagan Lake level management. Yellow triangle (Panel A) identifies preferred lower target for Okanagan Lake in late winter in advance of peak, spring-freshet inflows given an above-average snow-pack. Red lines (Panels C and D) are either observed or predicted seasonal inflows from unregulated tributary streams. Red triangles and black rectangles (Panel D) mark the sockeye egg/alevin scour and desiccation thresholds.

A. Okanagan Lake



B. Okanagan River at Penticton

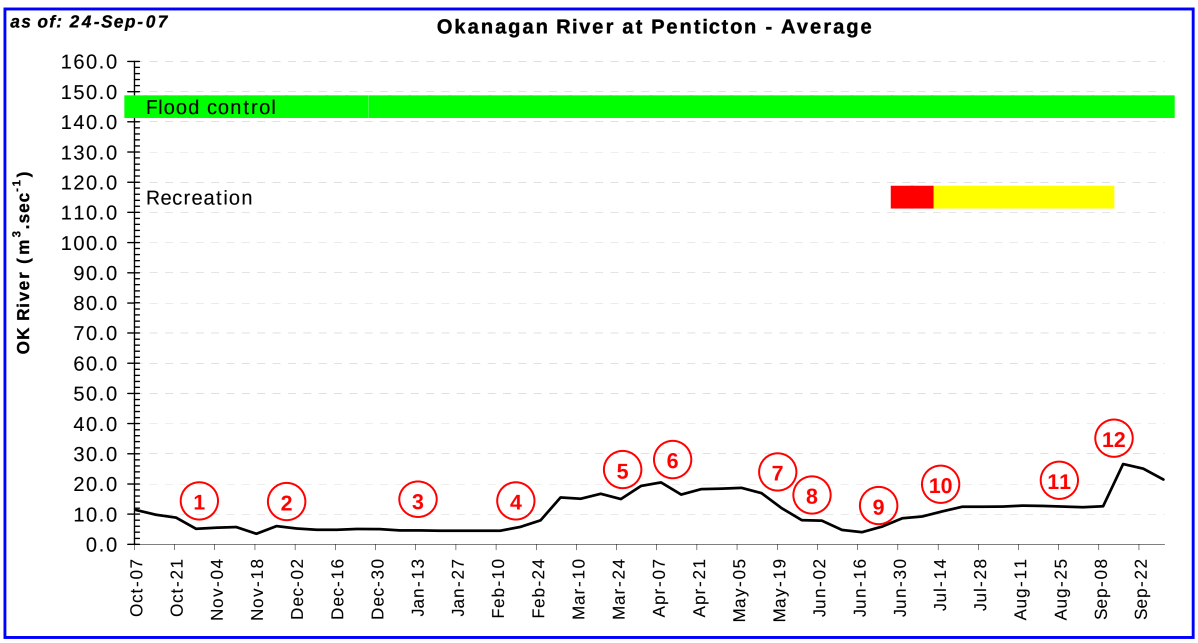
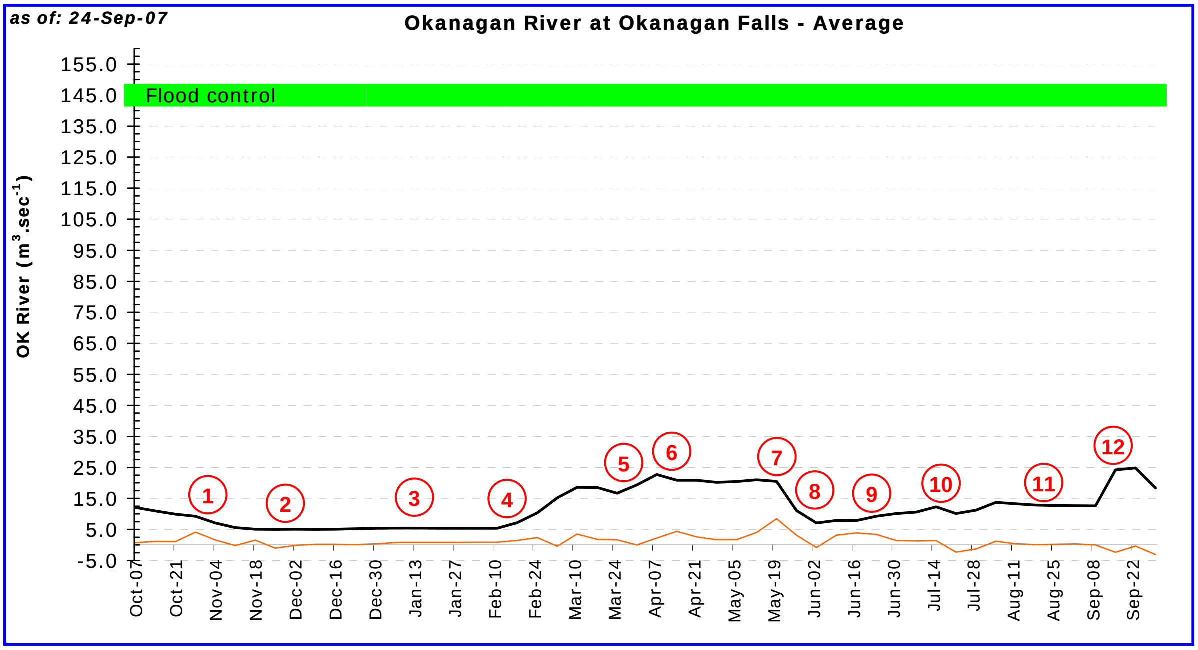
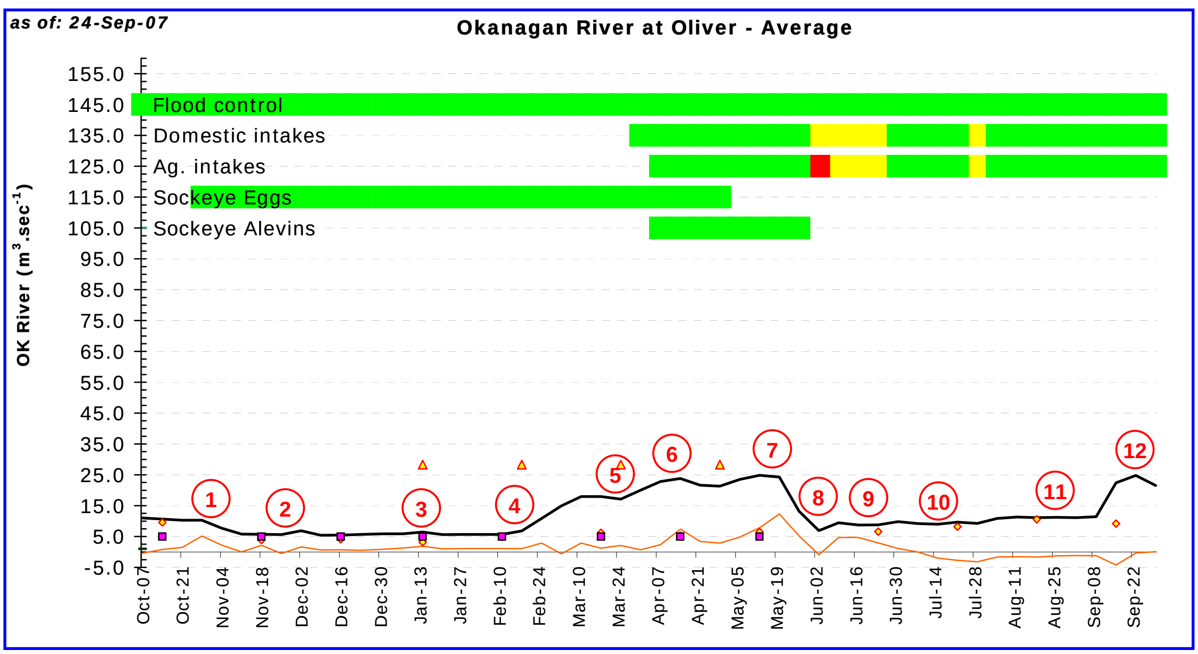


Figure 4. Final outcomes for (A) Okanagan Lake level and then, Okanagan River discharges at: (B) Penticton, (C) Okanagan Falls and (D) Oliver for the 2006-2007 FWMT fish-and-water management cycle respectively. **See Table 4 for commentary corresponding to bullet numbers.** Chart symbols are explained in Figure 3, above.

C. Okanagan River at Okanagan Falls



D. Okanagan River at Oliver



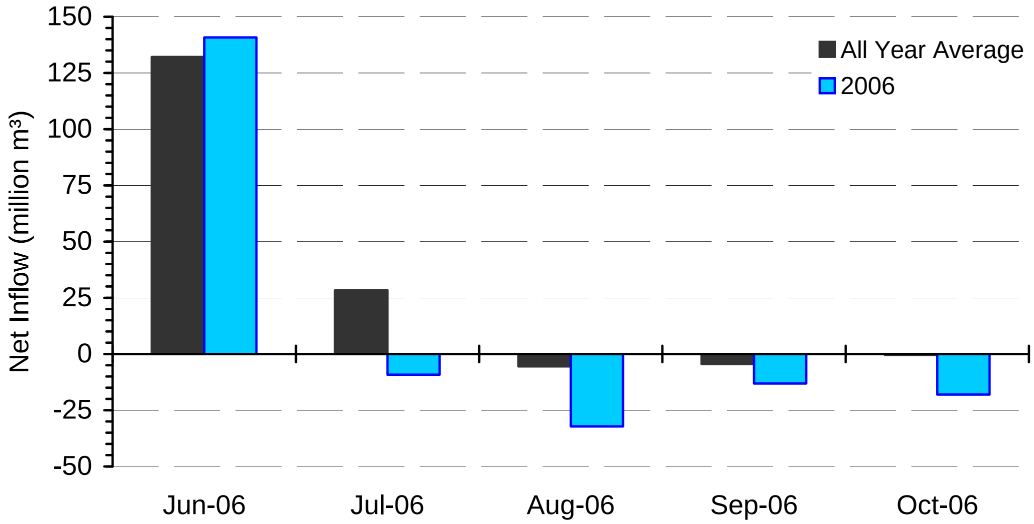


Figure 5. Net monthly inflows to Okanagan Lake during the summer of 2006 compared to the all year average (1974-2005). Negative inflows result from water withdrawals for irrigation and evaporative losses from Okanagan Lake.

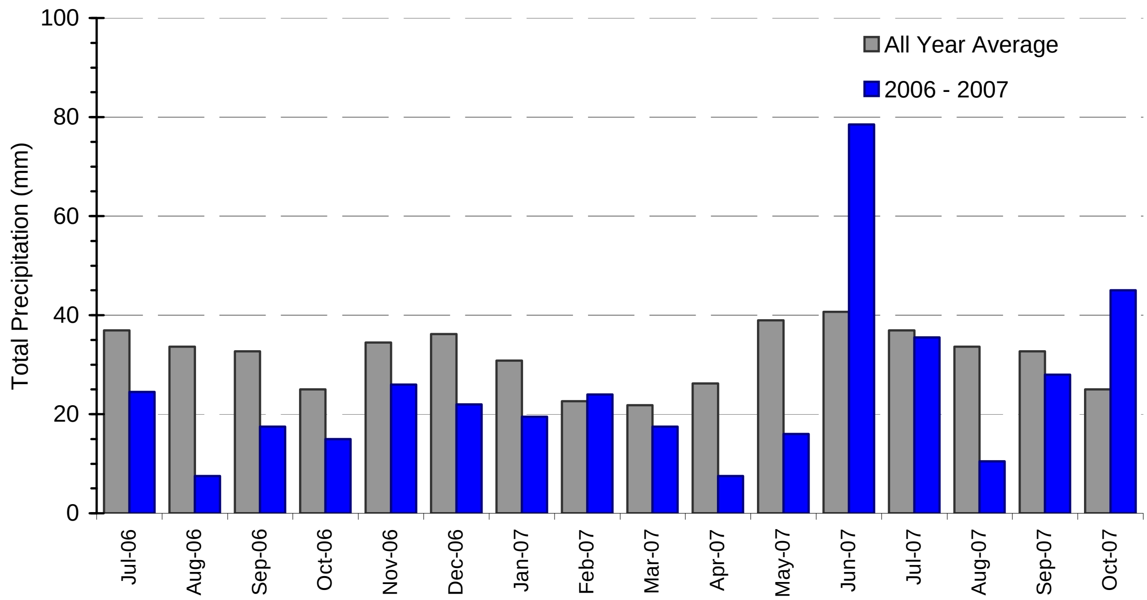


Figure 6. Total monthly precipitation (mm) at Environment Canada station Kelowna AWOS (1123965) from July 2006 to October 2007, including the corresponding all-year averages (1971-2000). Original data source: Environment Canada, Climate Data Online at: http://climate.weatheroffice.ec.gc.ca/climateData/canada_e.html (accessed 6-Aug-08).

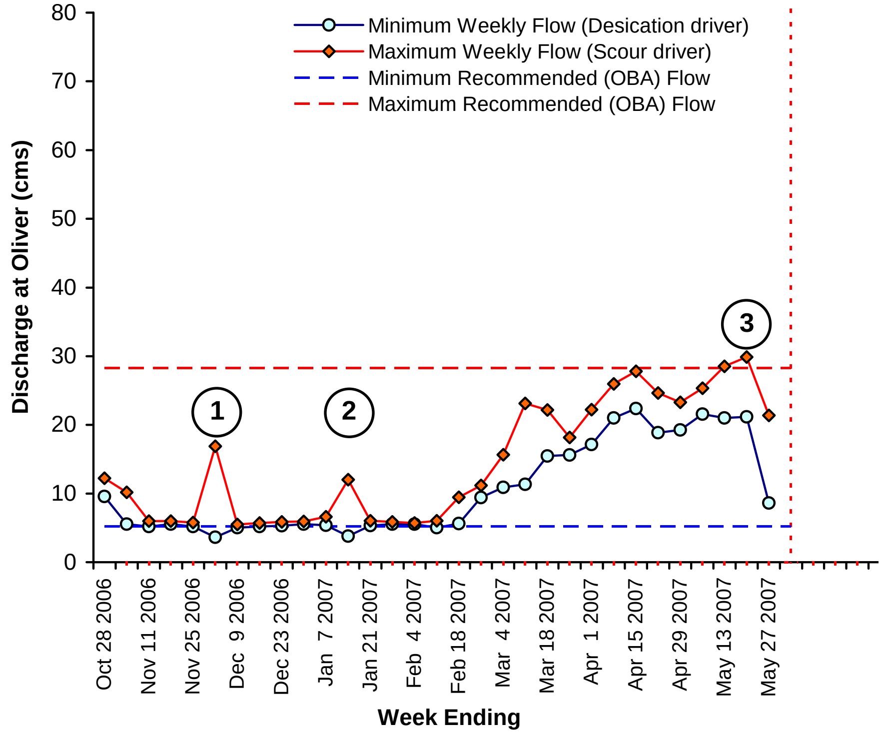
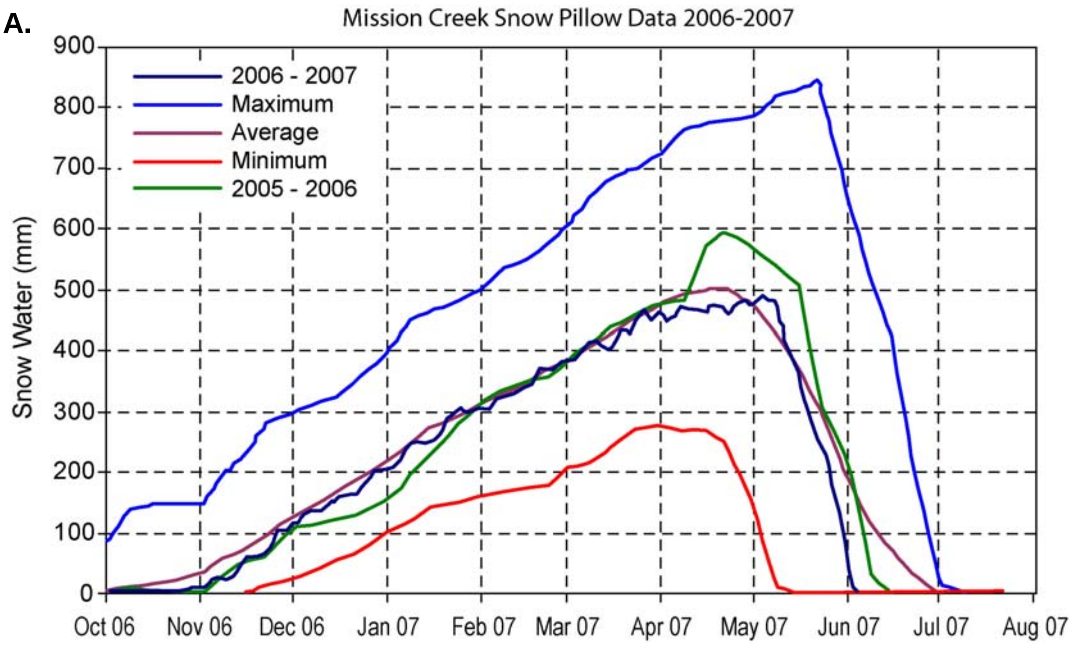


Figure 7. FWMT final output report for “Sockeye egg abundance over time” (2006-2007) which identifies potential desiccation and scour impacts from discharge rates occurring above or below recommended OBA levels (Table 1). Discharges are the instantaneous minimum and maximum achieved during the given week. The erratic spikes in scour driver (orange line) and drops to desiccation level flows (#1and #2) are false readings produced when icing caused the hydrometric gauge to malfunction for brief periods (< 0.5 day). Site inspections identified no changes to discharges which were consistently maintained at ~5.7cms (e.g. no risk to incubating sockeye eggs). Discharge rates on May 16 were slightly elevated (#3) above the scour threshold. However, field observations confirmed that sockeye emergence was complete by May 11 and fry were not exposed to risk.

A.



B.

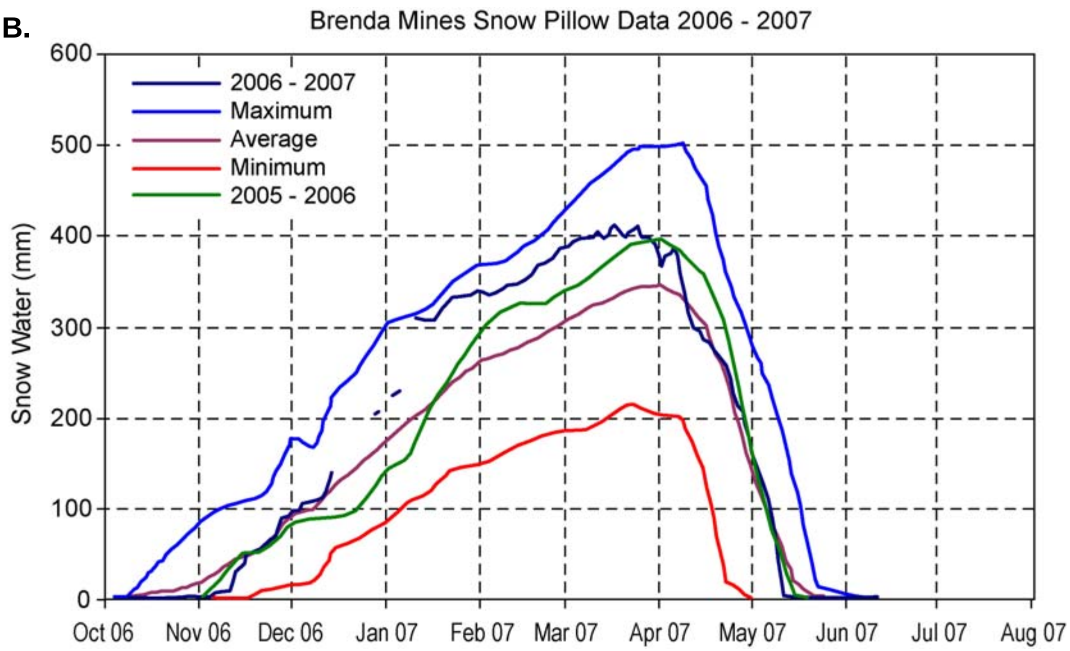


Figure 8. (A) Snow-water equivalents from high elevation (1794m) Mission Creek Snow Pillow station for water year 2007 (navy blue line) compared to all-year average, maximum and minimum values (37 years of record). (B) Snow-water equivalents from low elevation (1453m) Brenda Mine Snow Pillow station for water year 2007 (navy blue line) compared to all-year average, maximum and minimum values (15 years of record). Snow-pack from Mission Creek sub-basin contributes approximately one third of the annual net inflow to Okanagan Lake.
Source: BC Ministry of Environment, Water Stewardship Division available at: http://www.env.gov.bc.ca/rfc/river_forecast/spdokanagan.html (accessed 12-Jun-07).

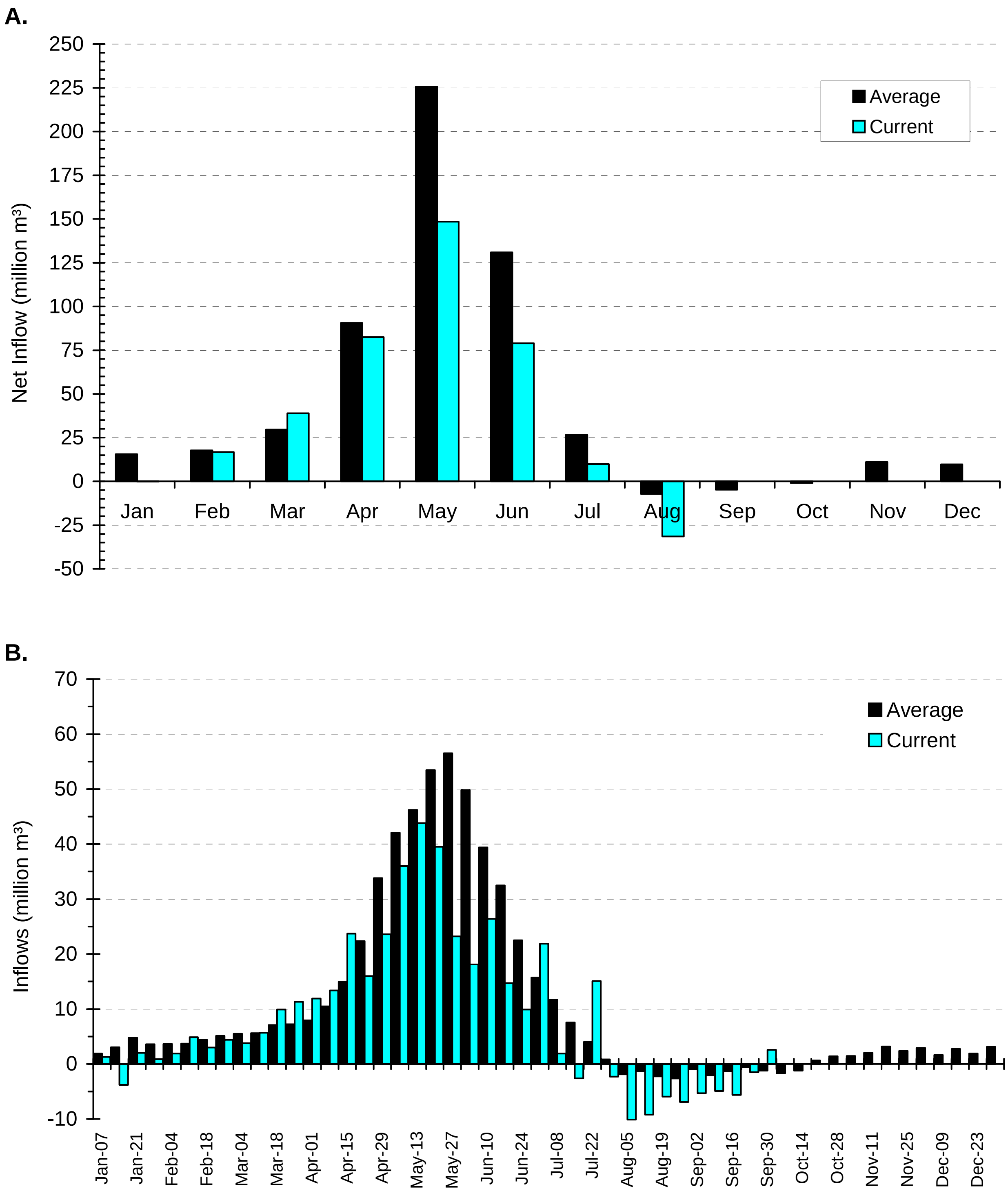


Figure 9. (A) Monthly and (B) weekly net inflows (in million m³) from all tributaries into Okanagan Lake for 2007 (blue bars) and the average across all years (black bars) from 1921-2006. Negative inflows in Aug-Sept result from water withdrawals for irrigation and evaporative losses from Okanagan Lake.

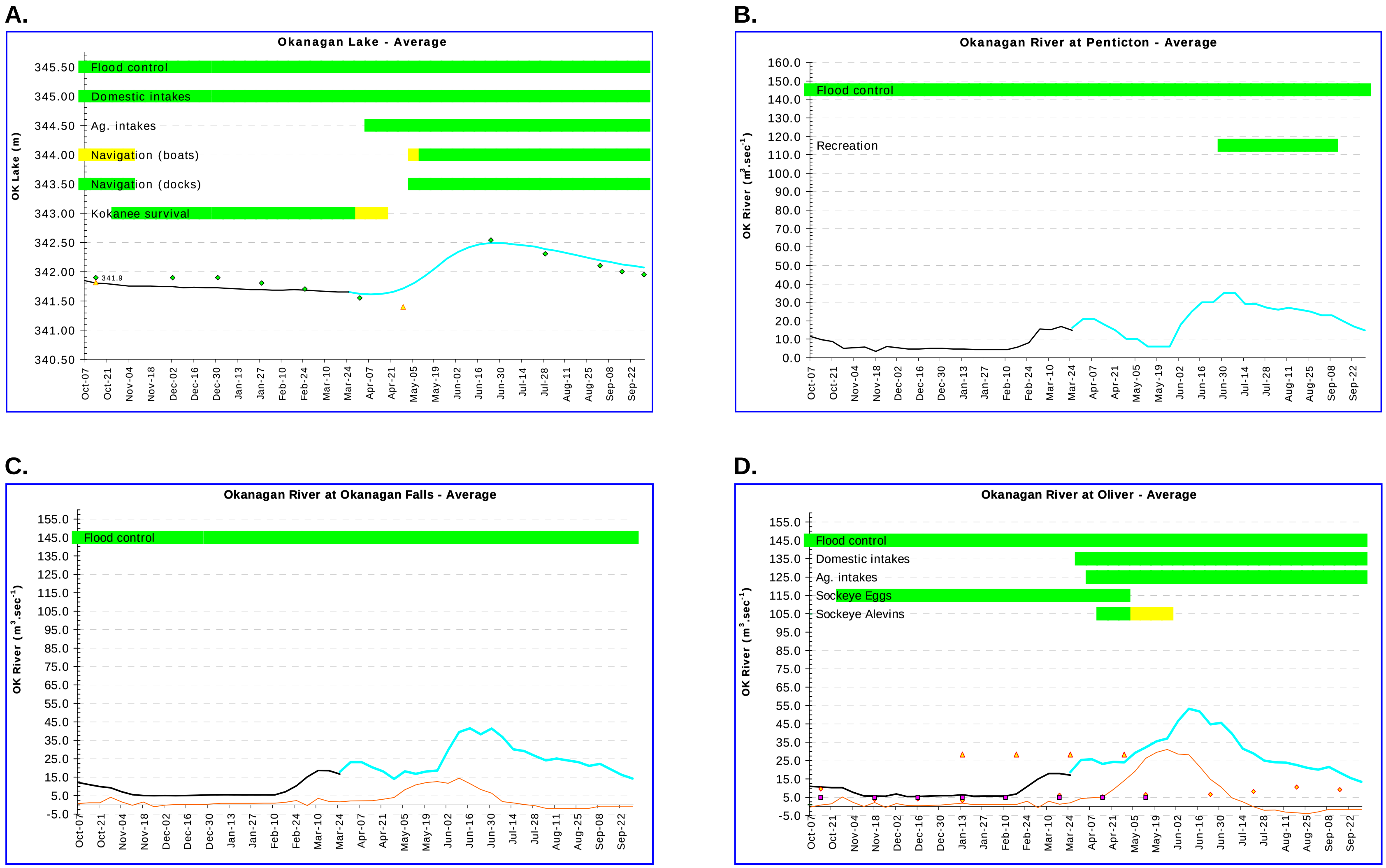


Figure 10. Results of FWMT Scenario 405 run by Kim Hyatt on March 25, 2007 depicting actual (black line) and predicted (blue line) observations of (A) Okanagan Lake levels and Okanagan River discharge at (B) Penticton, (C) Okanagan Falls and (D) Oliver. Chart symbols are explained in Figure 3.

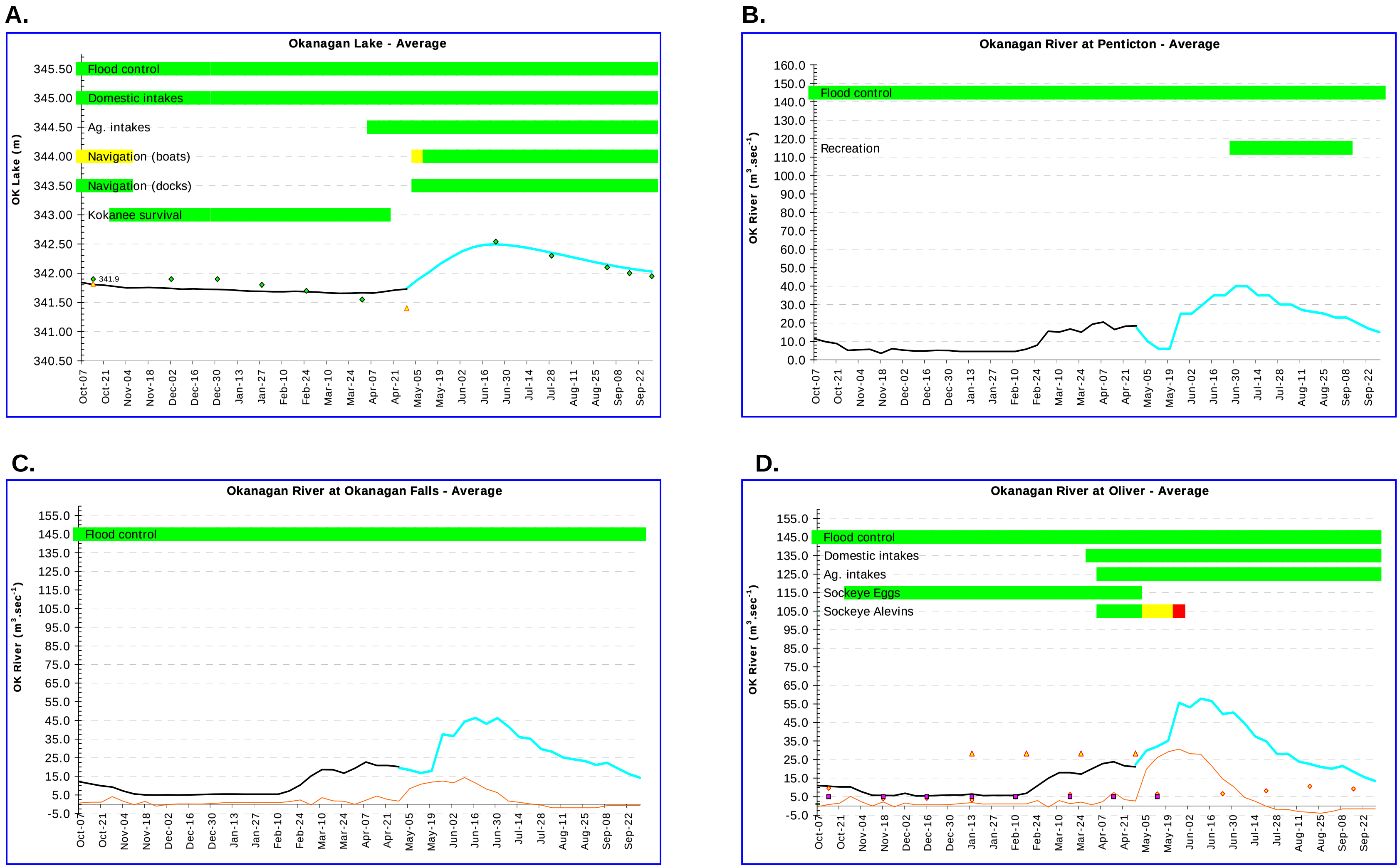
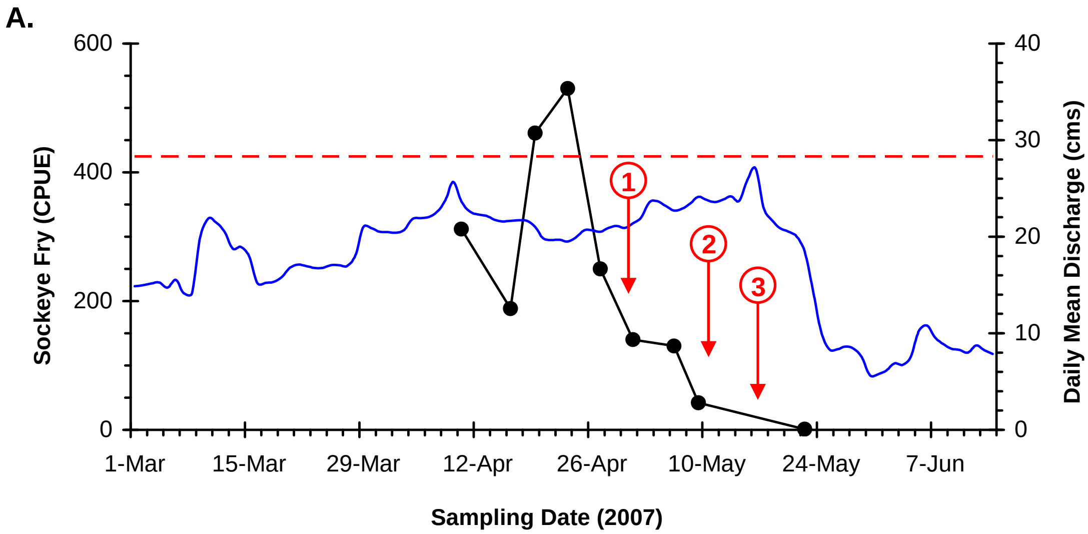


Figure 11. FWMT Scenario 416 run by Kim Hyatt on April 28, 2007 depicting actual (black line) and predicted (blue line) observations of (A) Okanagan Lake levels and Okanagan River discharge at (B) Penticton, (C) Okanagan Falls and (D) Oliver. Chart symbols are explained in Figure 3.



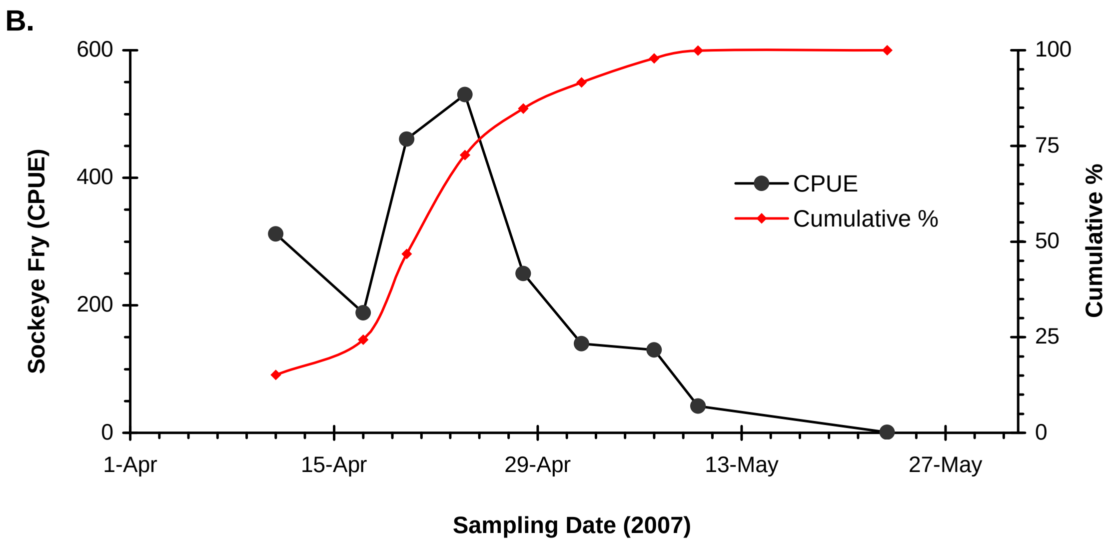


Figure 12. Okanagan River sockeye fry emergence in 2007 as determined by fyke net sampling at Vertical Drop Structure 13.

(A) Sockeye fry emergence (black line) and daily mean discharge rates (blue line) in the Okanagan River near Oliver during the spring of 2007. Sockeye emergence was successfully completed (May 11) without alevins/fry being subjected to scour inducing flows (>28.3 cms; red line). FWMT predicted the start of fry emergence as May 1 (#1), peak emergence on May 11 (#2) and 100% emergence on May 17 (#3).

(B) Time to 100% fry emergence as illustrated by cumulative catch as % of total catch across the entire sampling period.

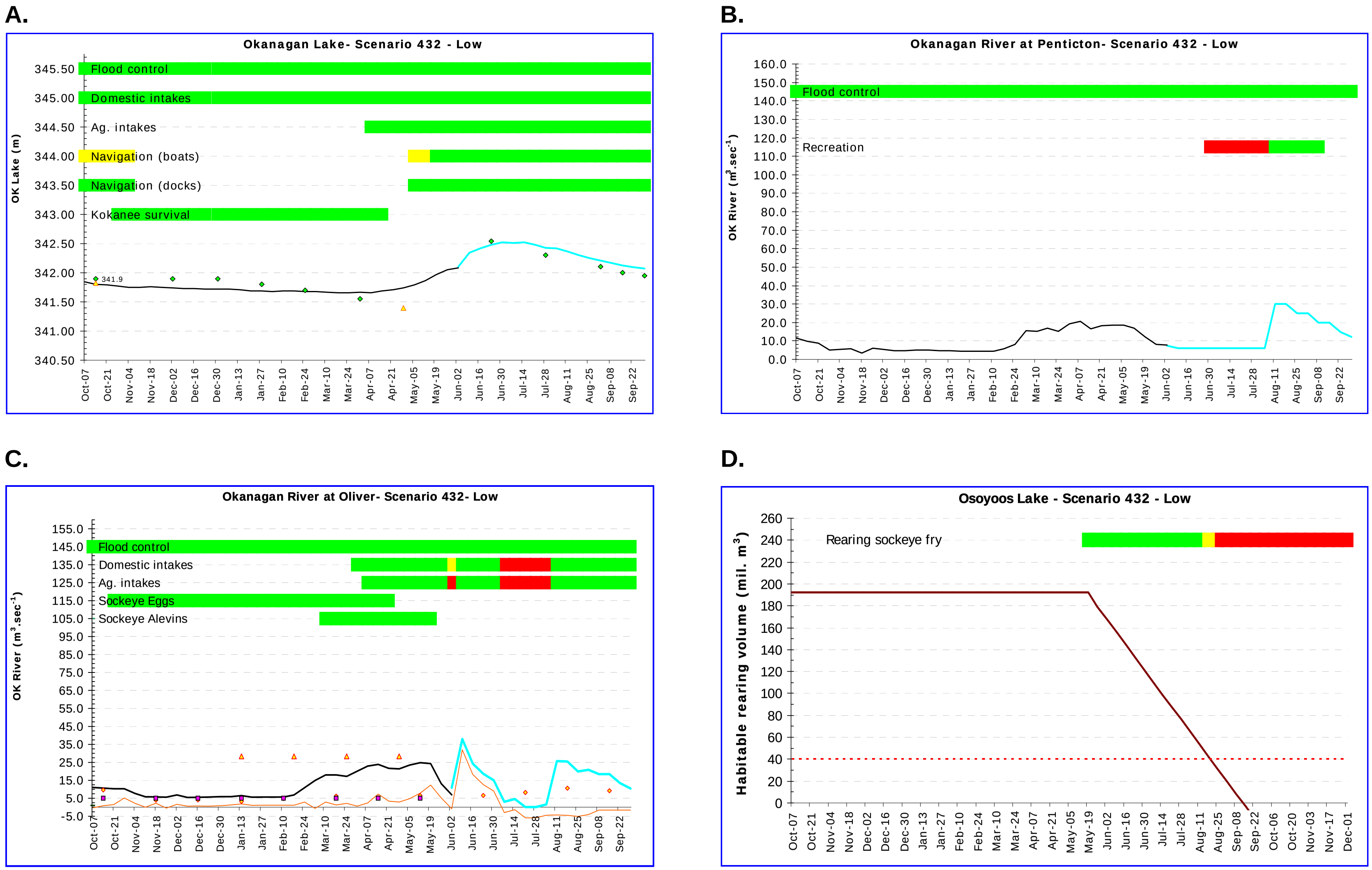


Figure 13. FWMT Scenario 432 run by Kim Hyatt on May 30, 2007 Chart symbols are explained in Figure 3. Graphs Low uses RFC inflow estimates (May 1 to July 31) that are 1 standard deviation below the all year average (Table 5).

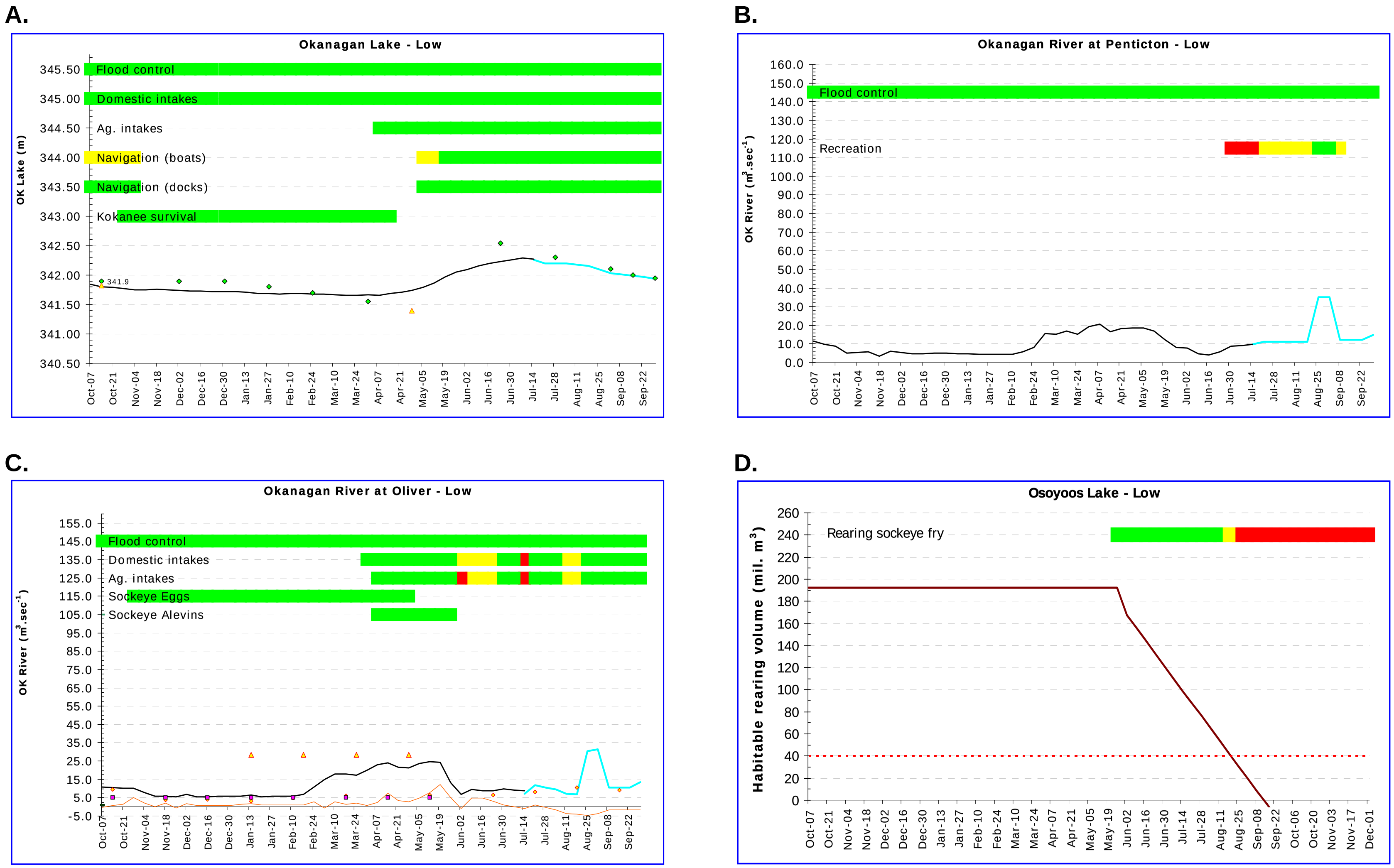


Figure 14. FWMT Scenario 430 run by Margot Stockwell on July 12, 2007 Chart symbols are explained in Figure 3. Graphs Low uses RFC inflow estimates (May 1 to July 31) that are 1 standard deviation below the all year average (Table 5).

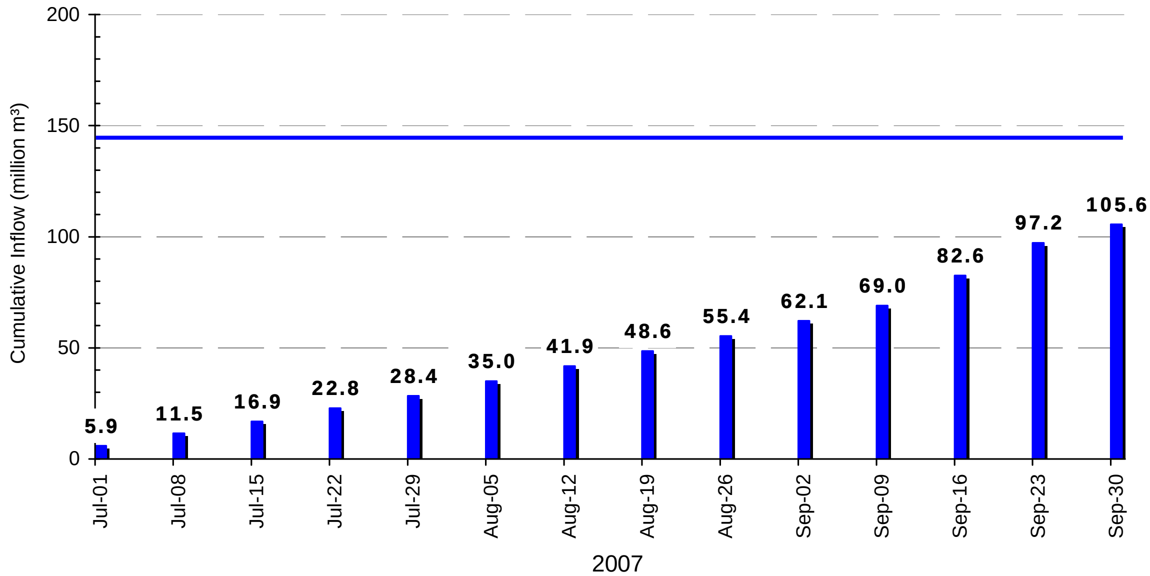


Figure 15. Cumulative inflow to Osoyoos Lake in the summer of 2007 relative to the cumulative July to September 145 million m³ minimum volume threshold (blue line) required to avoid a temperature-oxygen squeeze event (Alexander and Hyatt 2008). Inflow from July 1st to August 20th are actual values; inflows after August 20th are predicted values.

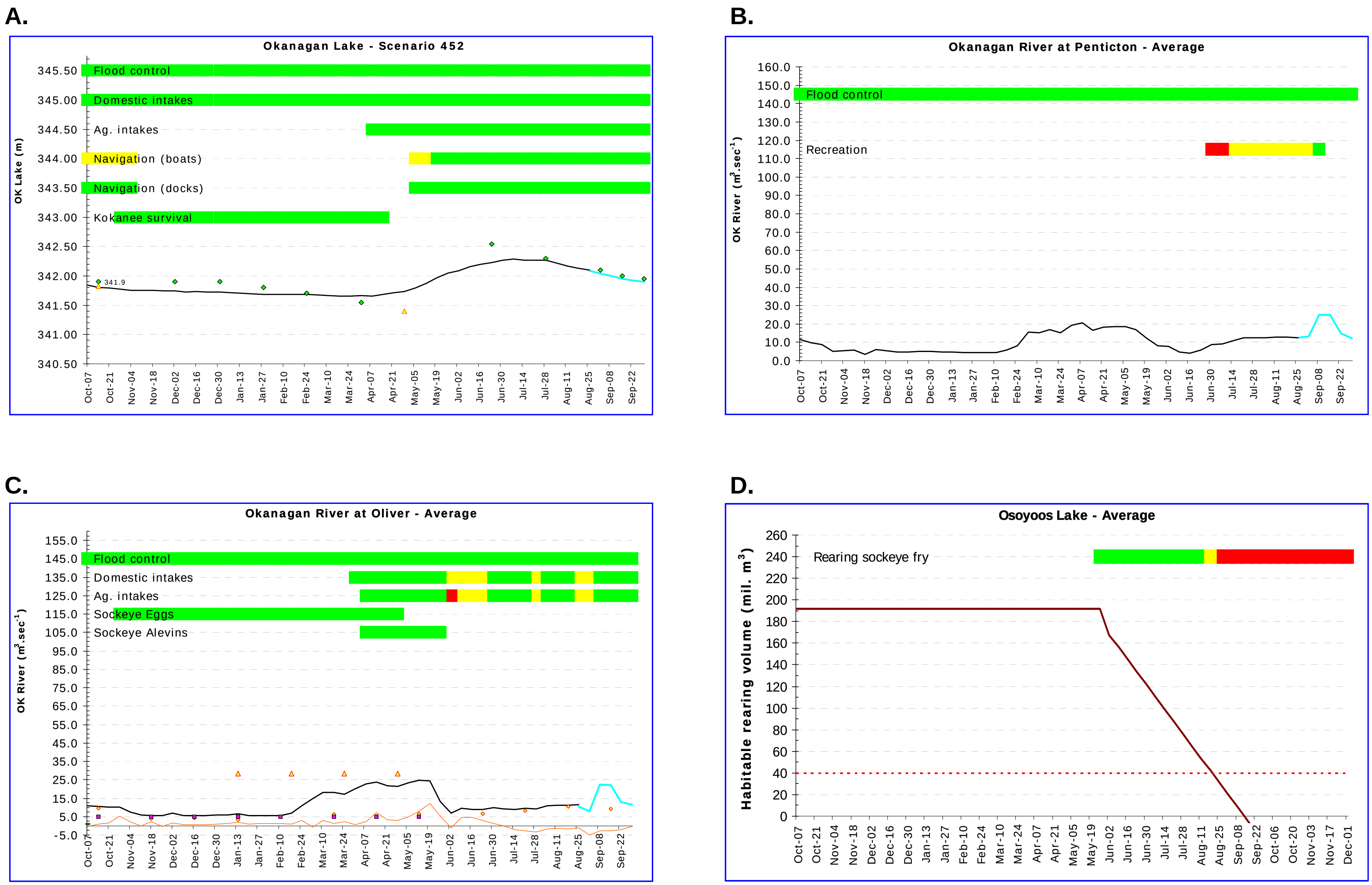


Figure 16. FWMT Scenario 452 run by Kim Hyatt on August 20, 2007 Chart symbols are explained in Figure 3.

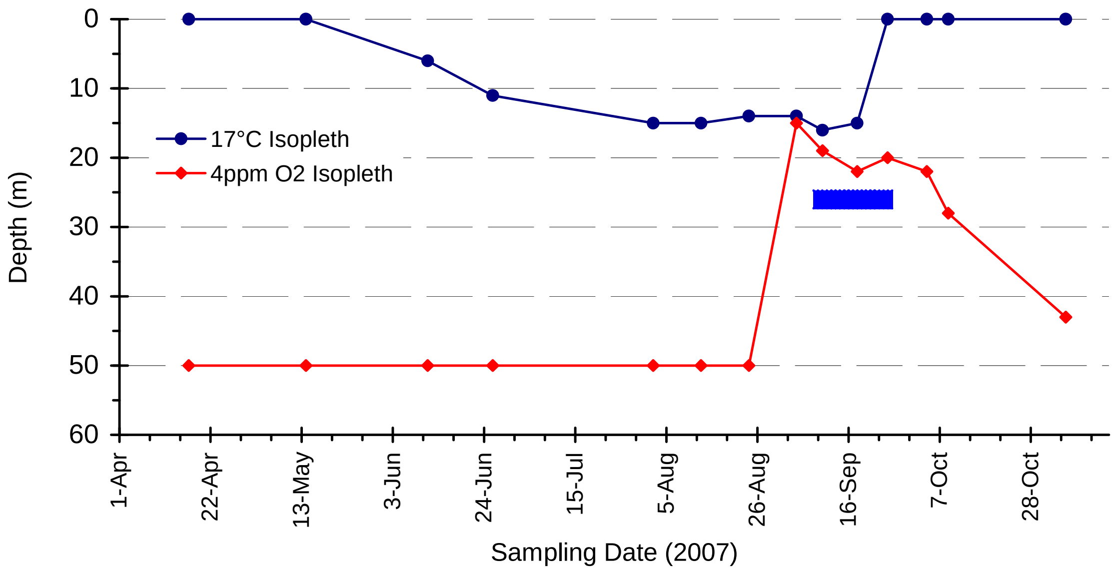


Figure 17. Depths of the 17°C and 4 ppm O_2 isopleths in the north basin of Osoyoos Lake during the summer of 2007. By the week of September 4th juvenile sockeye were restricted to a narrow, <1m band of habitable rearing volume. Retreat of the O_2 isopleth is associated with a "pulsed" release of water (25cms) between Sept. 10th and Sept. 24th (blue bar).

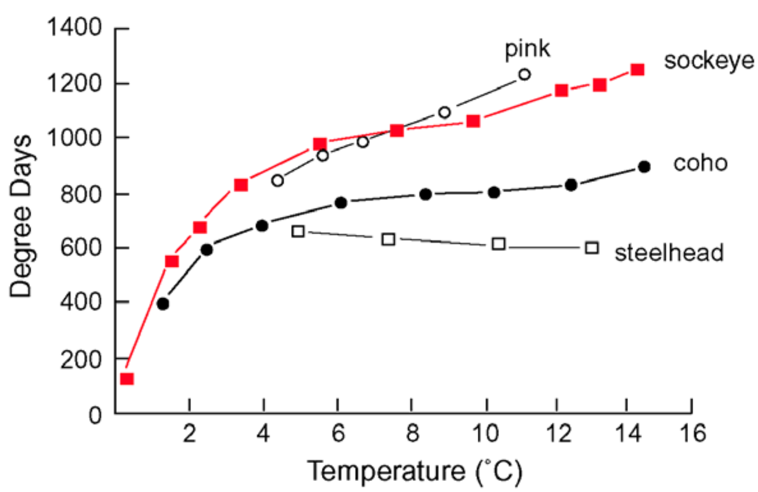


Figure 18. The relationship between temperature and degree days to yolk absorption for salmonids incubated at constant temperatures. (From: Brannon 1987).

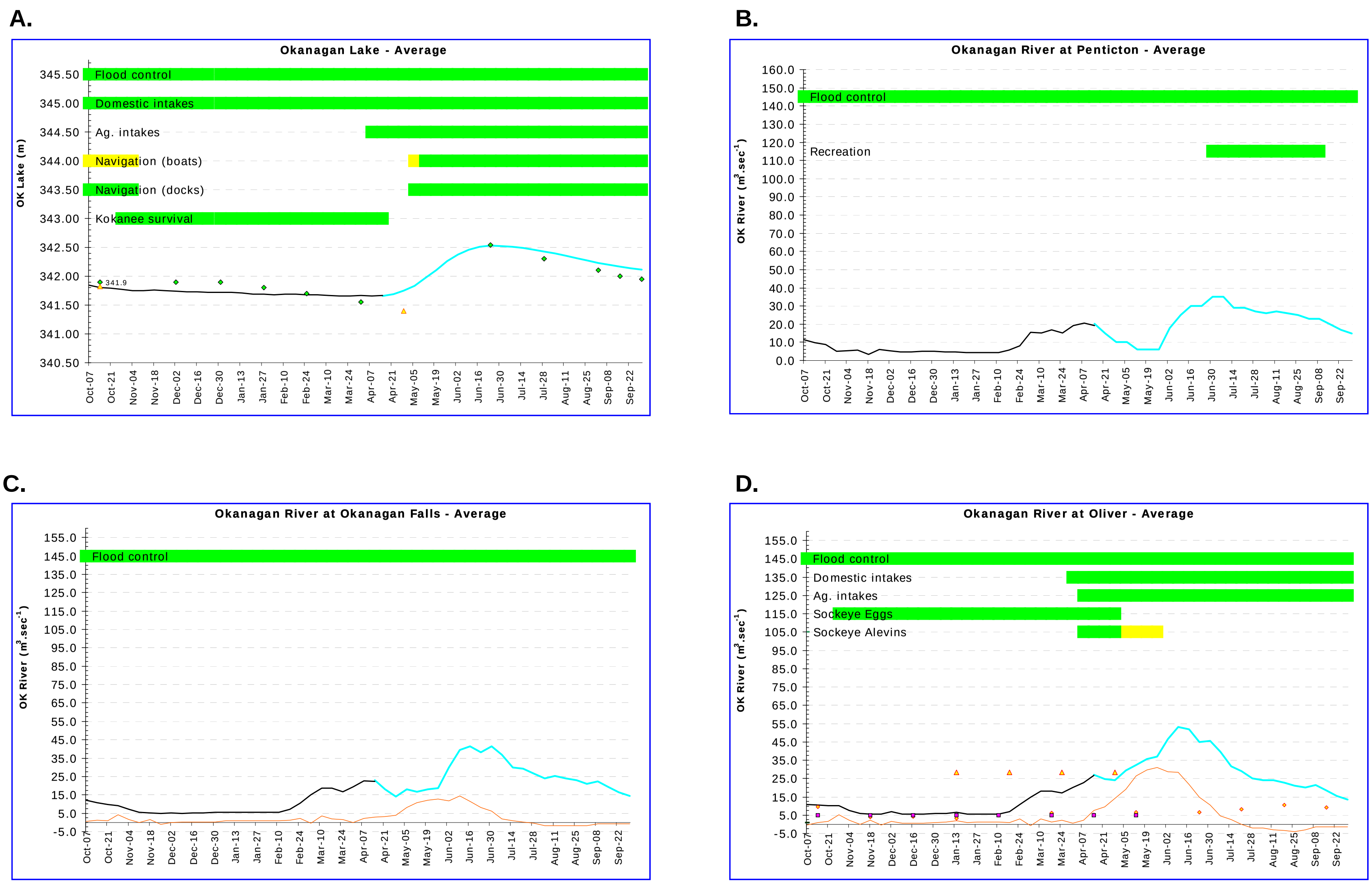


Figure 19. FWMT Scenario 408 run by Kim Hyatt on April 9, 2007 Chart symbols are explained in Figure 3.

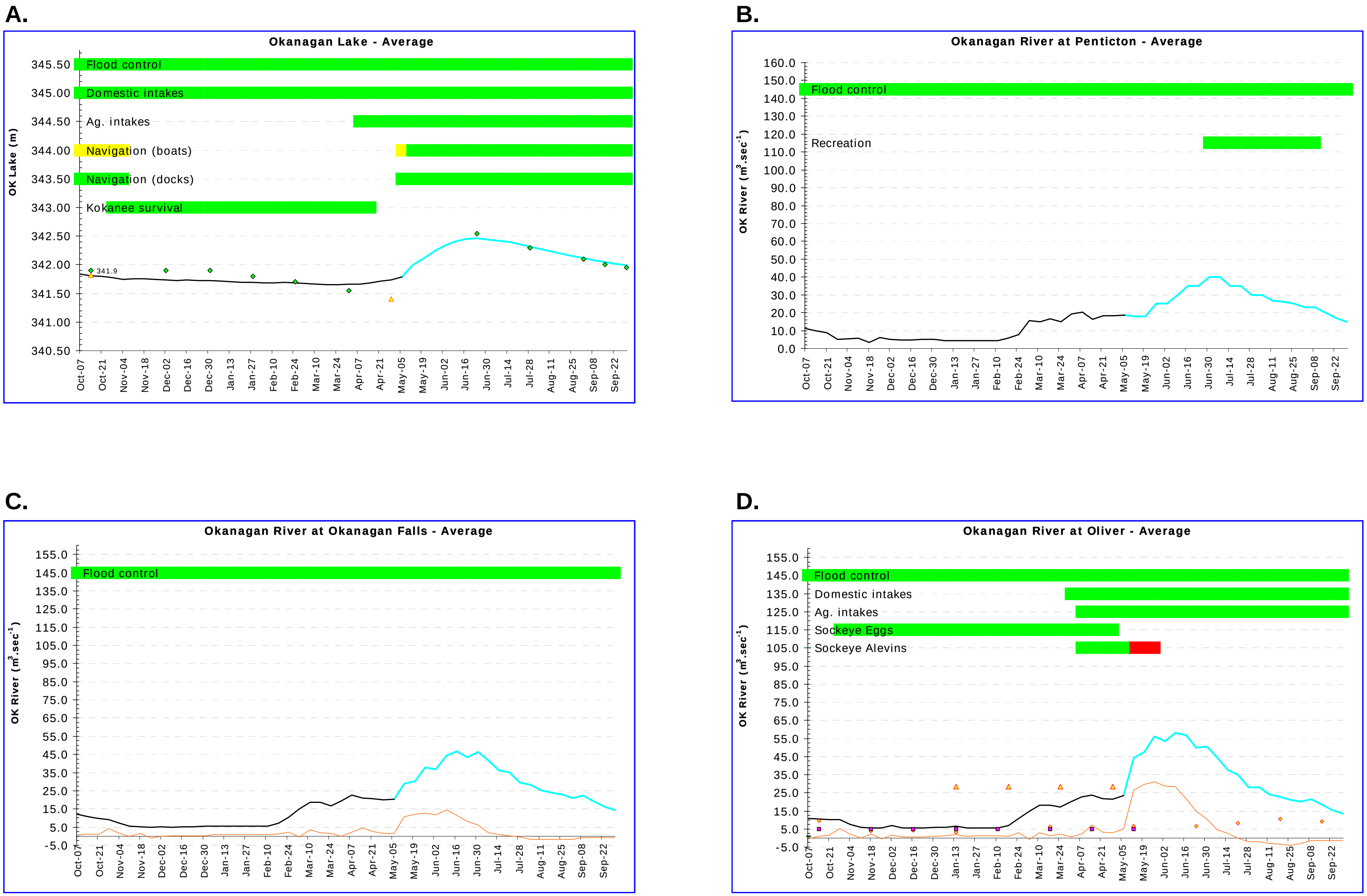


Figure 20. FWMT Scenario 421 run by Kim Hyatt on May 7, 2007 Chart symbols are explained in Figure 3.