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DEPARTMENT OF
WATER RESOURCES

Randall C. Budge, ISB #1949
Candice M. McHugh, ISB #5908
Thomas J. Budge, ISB #7465
RACINE OLSON NYE
BUDGE & BAILEY, CHARTERED
101 S. Capitol Blvd., Suite 300
Boise, Idaho 83702
Telephone: (208) 395-0011
rcb@racinelaw.net
cmm@racinelaw.net
tjb@racinelaw.net

Attorneys for Idaho Ground Water Appropriators, Inc.

BEFORE DEPARTMENT OF WATER RESOURCES

STATE OF IDAHO

IN THE MATTER OF DISTRIBUTION OF WATER TO WATER RIGHT NOS. 36-02551 & 36-07694 (RANGEN, INC.)	Docket No. CM-DC-2011-004 **AFFIDAVIT OF CANDICE McHUGH IN SUPPORT OF IGWA'S MOTION TO STRIKE PORTIONS OF EXHIBITS 1284 AND 1299 CONTAINING EXPERT OPINIONS OF CHARLES E. BROCKWAY, DAVID COLVIN, AND JIM BRANNON**

STATE OF IDAHO)
) ss.
COUNTY OF ADA)

Candice M. McHugh being fully sworn upon oath, deposes and states as follows:

1. I am one of the attorneys representing the Idaho Ground Water Appropriators, Inc. in the above-referenced matter and make the following Affidavit upon my personal knowledge of the facts and circumstances set forth herein.

1. Attached hereto as **Exhibit A** are true and correct copies of excerpts from the May 14, 2013 Rough Draft Hearing Transcript, Volume 10.

2 Attached hereto as **Exhibit B** are true and correct copies of excerpts from the deposition transcript of James H. Brannon, Jr. taken on March 4, 2013 (presented under seal).

3. Attached hereto as **Exhibit C** is the struck-out version of Exhibit 1284, the Opening Report.

4. Attached hereto as **Exhibit D** is the struck-out version of Exhibit 1299, the Rebuttal Report.

FURTHER, Affiant sayeth naught.

DATED this 22nd day of May, 2013.

Candice McHugh

CANDICE M. McHUGH

SUBSCRIBED and sworn to before me this 22nd day of May, 2013.

MARY TADDICKEN
NOTARY PUBLIC
STATE OF IDAHO

Mary Taddicken

Notary Public for Idaho
Residing at Boise, ID
My commission expires 9-12-13

CERTIFICATE OF SERVICE

I hereby certify that on this 22nd day of May, 2013, I caused to be served a true and correct copy of the foregoing upon the following by the method indicated:

Candice McHugh
Signature of person serving form

Original:
Director, Gary Spackman
Idaho Department of Water Resources
PO Box 83720
Boise, ID 83720-0098
Attn: Deborah Gibson
Deborah.Gibson@idwr.idaho.gov
Kimi.White@idwr.idaho.gov

☒ U.S. Mail/Postage Prepaid
☐ Facsimile
☐ Overnight Mail
☐ Hand Delivery
☒ E-mail

Garrick Baxter, Deputy Attorney General
Chris Bromley, Deputy Attorney General
Idaho Department of Water Resources
P.O. Box 83720
Boise, Idaho 83720-0098
garrick.baxter@idwr.idaho.gov
chris.bromley@idwr.idaho.gov

☐ U.S. Mail/Postage Prepaid
☐ Facsimile
☐ Overnight Mail
☐ Hand Delivery
☒ E-mail – without exhibits

Robyn M. Brody
Brody Law Office, PLLC
PO Box 554
Rupert, ID 83350
robynbrody@hotmail.com

☐ U.S. Mail/Postage Prepaid
☐ Facsimile
☐ Overnight Mail
☐ Hand Delivery
☒ E-mail - without exhibits

Fritz X. Haemmerle
Haemmerle & Haemmerle, PLLC
PO Box 1800
Hailey, ID 83333
fxh@haemlaw.com

☐ U.S. Mail/Postage Prepaid
☐ Facsimile
☐ Overnight Mail
☐ Hand Delivery
☒ E-mail – without exhibits

J. Justin May
May, Browning & May, PLLC
1419 West Washington
Boise, ID 83702
jmay@maybrowning.com

☐ U.S. Mail/Postage Prepaid
☐ Facsimile
☐ Overnight Mail
☐ Hand Delivery
☒ E-mail – without exhibits

Sarah Klahn
Mitra Pemberton
WHITE JANKOWSKI, LLP
511 16th St., Suite 500
Denver, Colorado 80202
sarahk@white-jankowski.com
mitrap@white-jankowski.com

☐ U.S. Mail/Postage Prepaid
☐ Facsimile
☐ Overnight Mail
☐ Hand Delivery
☒ E-Mail – without exhibits

Dean Tranmer City of Pocatello PO Box 4169 Pocatello, ID 83201 dtranmer@pocatello.us	☐ U.S. Mail/Postage Prepaid ☐ Facsimile ☐ Overnight Mail ☐ Hand Delivery ☒ E-Mail – without exhibits
C. Thomas Arkoosh ARKOOSH EIGUREN LLC PO Box 2900 Boise, ID 83701 tom.arkoosh@aelawlobby.com	☐ U.S. Mail/Postage Prepaid ☐ Facsimile ☐ Overnight Mail ☐ Hand Delivery ☒ E-Mail – without exhibits
John K. Simpson Travis L. Thompson Paul L. Arrington Barker Rosholt & Simpson 195 River Vista Place, Suite 204 Twin Falls, ID 83301-3029 tlt@idahowaters.com jks@idahowaters.com pla@idahowaters.com	☐ U.S. Mail/Postage Prepaid ☐ Facsimile ☐ Overnight Mail ☐ Hand Delivery ☒ E-Mail – without exhibits
W. Kent Fletcher Fletcher Law Office PO Box 248 Burley, ID 83318 wkf@pmt.org	☐ U.S. Mail/Postage Prepaid ☐ Facsimile ☐ Overnight Mail ☐ Hand Delivery ☒ E-Mail – without exhibits
Jerry R. Rigby Hyrum Erickson Robert H. Wood Rigby, Andrus & Rigby, Chartered 25 North Second East Rexburg, ID 83440 jrigby@rex-law.com herickson@rex-law.com rwood@rex-law.com	☐ U.S. Mail/Postage Prepaid ☐ Facsimile ☐ Overnight Mail ☐ Hand Delivery ☒ E-Mail – without exhibits

Rangen Hearing 2013

Rough Draft - Hearing - May 14, 2013 (Day 10)

5/14/2013

Full-size Transcript

Prepared by:

Becky Harvey
Racine Olson Nye Budge & Bailey, Chtd

Monday, May 20, 2013

Exhibit A

Warning! The following is a rough draft of the within deposition transcript which has been provided upon request with the specific understanding and acknowledgment that:

Such Transcript is not in final form and is not an official transcript of the proceeding. The nature of stenographic writing necessitates that the reporter may have to make various corrections and/or changes as a result of human error and/or stenographic notes not being fully translated by the equipment from steno to English. As a result the final transcript my vary significantly.

Such transcript is being provided as a special service, to be used for limited purposes as may be appropriate in the discretion of the recipient; however, the reporter and/or M & M Court Reporting Services, Inc., will not be responsible for any of the content of such transcript and/or any variance from the final official transcript.

BEFORE THE DEPARTMENT OF WATER RESOURCES

OF THE STATE OF IDAHO

IN THE MATTER OF DISTRIBUTION OF)
WATER TO WATER RIGHT NOS. 36-02551) Docket No.
AND 36-07694) CM-DC-2011-004
)
(RANGEN, INC.)) VOLUME X
____________________________________) (Pages ****-****)

C O N F I D E N T I A L

Pursuant to Protective Order Dated August 31, 2012

BEFORE

HEARING OFFICER: GARY SPACKMAN

Date: May 14, 2013 - 8:49 a.m.

Location: Idaho Department of Water Resources
322 East Front Street
Boise, Idaho

REPORTED BY:

JEFF LaMAR, C.S.R. No. 640

Notary Public

APPEARANCES:

For Rangen, Inc.:

MAY, BROWNING & MAY
BY MR. J. JUSTIN MAY
1419 West Washington
Post Office Box 6091
Boise, Idaho 83707
-and-
HAEMMERLE & HAEMMERLE, PLLC
BY MR. FRITZ X. HAEMMERLE
Post Office Box 1800
Hailey, Idaho 83333
-and-
BRODY LAW OFFICE, PLLC
BY MS. ROBYN M. BRODY
Post Office Box 554
Rupert, Idaho 83350

For City of Pocatello:

WHITE & JANKOWSKI, LLP
BY MS. SARAH A. KLAHN
MR. J. RYLAND HUTCHINS
511 Sixteenth Street, Suite 500
Denver, Colorado 80202

///

APPEARANCES (Continued):

For Idaho Groundwater Appropriators:

RACINE, OLSON, NYE, BUDGE & BAILEY, CHARTERED

BY MR. THOMAS J. BUDGE

MS. CANDICE M. McHUGH

101 South Capitol Boulevard, Suite 300

Boise, Idaho 83702

For Surface Water Coalition:

BARKER, ROSHOLT & SIMPSON LLP

BY MR. JOHN K. SIMPSON

1010 West Jefferson, Suite 102

Post Office Box 2139

Boise, Idaho 83701-2139

-and-

ARKOOSH LAW OFFICES

BY MR. C. THOMAS ARKOOSH

Post Office Box 2900

Boise, Idaho 83701

For Fremont-Madison Irrigation District:

RIGBY, ANDRUS & RIGBY, CHARTERED

BY MR. JERRY R. RIGBY

25 North Second East

Rexburg, Idaho 83440

///

APPEARANCES (Continued):

For Idaho Department of Water Resources:

OFFICE OF ATTORNEY GENERAL
IDAHO DEPARTMENT OF WATER RESOURCES
BY MR. CHRISTOPHER M. BROMLEY
322 East Front Street
Boise, Idaho 83720

I N D E X

W I T N E S S E S

E X H I B I T S

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I N D E X (Continued)

E X H I B I T S

testimony that we restricted access to the questioning. And I suspect that these are areas you want to explore Ms. McHugh.

MS. McHUGH: Yeah, I just wanted to confirm what he was not offering opinions in.

THE HEARING OFFICER: And I suppose in addition, you know, you'll have flexibility in having Dr. Brockway present his rebuttal testimony in a desire not to have him come back I think would be cause to at least go beyond the scope of some of the examination. Objection overruled.

MS. McHUGH: Thank you.

Q. Just to confirm that in this case and in your reports that are here that you are not offering an opinion as an expert in aquaculture or fish production; is that true?

A. Not as it relates to the economic or the physiology of fish rearing. As it relates to water management relative to fish, I am.

Q. You did not review any of Rangen's fish-production records; correct?

A. Did I not.

Q. And you have no opinion regarding the amount of water Rangen needs for fish propagation purposes?

A. Not for specific purposes, no.

Q. And you don't know if Rangen could raise more fish with current water supply; correct?

A. I have an opinion that he could, yes.

Q. You would agree that fish propagation is not your area of expertise; correct?

A. Well, fish propagation is a pretty broad topic. If you want to expand on that, I might be able to narrow my opinion down.

MS. McHUGH: Jeff, could I have you get Mr. Brockway's deposition.

THE HEARING OFFICER: Off the record. (recess).

Q. (BY MS. McHUGH): Dr. Brockway could I have you turn -- in front of you you've been handed a copy of your deposition taken March 6?

A. , 2,013.

A. Yes.

Q. Do you recall having your deposition taken on March 6th, 2,013?

A. Yes.

Q. Could I have you turn to page 172?

A. Okay.

Q. And if you look at line 18. I'll read the question if you could read the answer. Question, are you offering an opinion on the amount of water Rangen needs for fish propagation purposes. Your answer?

A. I must have the wrong page.

Q. Page 172.

A. Line what.

Q. Starting on line 18?

A. Oh, yeah, okay.

Q. I'll do that again. Question, are you offering an opinion on the amount of water Rangen needs for fish propagation purposes? Your answer?

A. No.

Q. Question, is it your opinion that Rangen optimizes fish production at its facility. Answer?

A. I have no opinion on that.

Q. Could I have you turn turn to page 97 of your deposition., line 5. Are you there, Dr. Brockway?

A. Yes.

Q. Question, down if Rangen could raise additional fish with there existing water supply. Answer?

A. I don't know that, no.

Q. You did not review any of Rangen's research records for your opinions in this case; is that true?

A. Did I not.

Q. Awe r-and you don't know any details of Rangen's research efforts?

A. I don't know the details, no.

Q. And you're not offering an opinion on how much water Rangen needs for research purposes; is that correct?

A. Not specifically for research purposes.

Q. And you have no opinion on how much water Rangen needs to raise the same number of fish they did in the past?

A. I can't tell you how many cfs it takes to raise a thousand pounds of fish, no.

Q. Okay. And then that helps right there. And then as far as Mr. Director, with that background in mind, there are places in Dr. Brockway's reports where he offers opinions about aquaculture industry standards, the amount of water need today rehabilitate there research facilities and those kinds of things. I can point you specifically to those portions of his report and ask that they be struck or given due weight, given the fact in light of his current testimony or I can rely on you to understand that based on his testimony what portions of his report he would not be competent to offer opinions in?

THE HEARING OFFICER: Okay, I guess I want to ask the parties how they want to address these kinds of issues in reports that are already received into significant, wouldn't you agree?

A. You could raise some fish with that, yes.

Q. So if we went from underpredicting flows in the early period to overpredicting flows at the end, isn't that right, based on this residual graph?

A. That's what that would tell you, yes.

Q. And why would that be? Because something changed on the ESPA?

A. Well, yes, something.

Q. But the model doesn't currently have anything in it to compensate for that, correct, whatever that change is?

A. Well, the compensate or for it wouldn't be there.

Q. Thank you. That's all I have.

THE HEARING OFFICER: Ms. McHugh.

MS. McHUGH: Nothing further. Thank you.

THE HEARING OFFICER: Mr. Rigby?

MR. RIGBY: No, Mr. Director.

THE HEARING OFFICER: Okay. Thank you, Mr. Brockway. Next witness?

MR. MAY: I'm going to call Dave Colvin VIN.

THE HEARING OFFICER: Okay. Very good. Mr. Colvin. And we have some question about Mr. Sullivan and his testimony today.

MS. KLAHN: We don't need to do it today now that we have the whole week.

THE HEARING OFFICER: Okay. Mr. Sullivan is taking up residency, I assume.

MS. KLAHN: He's probably not happy to hear that. We can probably do it tomorrow. Let's not interrupt Rangen's pre rebuttal.

MR. MAY: I was going to say he took up residence awhile ago. He's been here awhile.

THE HEARING OFFICER: Raise your right hand please (swear swear).

THE WITNESS: Yes.

THE HEARING OFFICER: Thank you. Please be seated?

Q. (BY MR. MAY): Good afternoon, Mr. Colvin. Could you please state -- state your name for the record and spell your last name?

A. My name is David Colvin. Last name is spelled c-o-l-v-as in victor i-n-

Q. And where do you currently reside?

A. Colorado Louisville Colorado.

Q. Where are you ly currently employed?

A. Leonard Rice Engineers.

Q. I've got up on the screen I'm going to show to you what's been marked as Exhibit 1271. Do you recognize this document?

A. Yes, that's my resumé.

Q. Okay. And could you talk about your education starting with college?

A. Sure. I've got a bachelor of science in geology from Syracuse University and a master's of science in environmental science and engineering from Colorado School of Mines.

Q. And if you could, would you walk us through a little bit some of your work experience related to the matters on which you're going to be offering testimony today?

A. The work I've done in the past is primarily hydrogeology as it relates to aquifer characterization, testing, and groundwater modeling.

Q. And where did you -- where did you perform that work, where have you had that work experience?

A. Various companies, including at the time raw tech and geo mega and various locations *CHECK SPELLING*, mostly throughout Colorado and the west.

Q. And you mentioned hydrogeology and also modeling. Do you have any particular training in modeling, groundwater modeling?

A. I do. I took classes in groundwater modeling, two classes in graduate school and then significant change on the effects at Rangen; right?

A. Using an erroneous prediction minimization as a target, yes, it did. And...

Q. Aside from your opinion regarding the prediction target?

A. Yes.

Q. Setting that aside, if half of the -- if the model has changed in a manner that allowed half of the model domain parameters to be changed, you would expect that to have more of an impact than changing parameters than just a few handful of cells arounds Rangen?

A. If it were calibrated may be.

Q. Okay. Under the composite model did you compare calibration at other spring targets besides the Rangen Spring?

A. I did not.

Q. Okay. Let me ask a you few questions, some of these were asked of Dr. Brockway and we covered these in your deposition. So I know the answers, but we need them for the purpose of clarifying the record what your area of expertise is and opinions you're offering?

A. Sure.

Q. You don't have any opinions regarding fish production?

A. No.

Q. Or water quality?

A. No.

Q. No engineering opinions?

A. No.

Q. You didn't review any fish-production records for Rangen?

A. No.

Q. Or research records?

A. No.

Q. You don't have an opinion on aquaculture industry standards?

A. No.

Q. Or fish hatchery management?

A. No.

Q. Okay. You didn't make any investigation of the feasibility of utilizing vertical wells above the rim to supplement Rangen's water supply?

A. We reviewed the alternatives presented in our initial expert report. We reviewed them in a conceptual sense.

Q. Okay. But you did not make any investigations of the physical feasibility of using vertical wells to augment Rangen's water supply?

BEFORE THE DEPARTMENT OF WATER RESOURCES

OF THE STATE OF IDAHO

IN THE MATTER OF DISTRIBUTION OF WATER TO WATER RIGHT NOS. 36-02551 AND 36-07694	)	**CM-DC-2011-004**
(RANGEN, INC.)	)	

CONFIDENTIAL INFORMATION

The enclosed is subject to the terms of the *Protective Order* entered on August 31, 2012 and is being disclosed pursuant to its terms. The enclosed documents may not be used other than in connection with the above-referenced delivery call.

Project No. 1159-01-2011 and 1179MSB01

Expert Report in the Matter of Rangen Inc. - Availability of Spring Flow and Injury to Water Rights

Prepared for:

Rangen, Inc.

December 20, 2012

PROFESSIONAL ENGINEER
REGISTERED
4699
12/17
STATE OF IDAHO
CHARLES E. BROCKWAY

~~*Charles E. Brockway, Ph.D., P.E. Brockway Engineering*~~

David Colvin, P.G. Leonard Rice Engineers David C. Colvin, P.G.

Jim Brannon, Brannon Developments

EXHIBIT
1284
CM-DC-2011-004

Exh. No. 154
Date 3/4/13
Name Brannon
M & M Court Reporting

Exhibit C

Table of Contents

List of Figures

List of Tables

Appendices

A. Background

Rangen Inc. (Rangen) submitted a new Petition for Delivery Call to the Idaho Department of Water Resources (IDWR) on December 13, 2011 requesting relief from material injury to spring flow water rights held by Rangen. This Petition addressed the injury to Rangen's water rights 36-02551 and 36-07694 for the Rangen Aquaculture Research Center (Research Hatchery).

This report addresses the procedures and analytical approaches documenting the injury to the Rangen water rights and the procedures which the Department utilized in evaluating the trends in historical discharge and the seasonal and pumping-impacted variability in discharge of the Rangen water supply at the time of appropriation. The report outlines alternative procedures to evaluate spring responses and injury resulting from changes in water use on the ESPA, particularly the pumping of ground water by junior water right holders. The report also addresses the particulars of the recently completed ground water model, ESPAM 2.1, and the methods of utilizing the model to determine impacts or injury to existing spring water rights and appropriate uses for the model. Figure 1 shows the location of the Rangen facility.

The previous determination (Second Amended Order of May 19, 2005) of the estimated increase at Rangan Spring at steady state with the effective response constrained to wells providing more than 10% of pumped volumes was 0.4 CFS. The best available science for predicting beneficial impacts of curtailing ground water pumpers junior to July 13, 1962 is ESPAM 2.1. ESPAM 2.1 predicts a steady state impact of 17.9 CFS from curtailment of ground water pumping within the area of the model, under water rights junior to July 13, 1962. The measured average flow available to Rangen over the last 10 years is 14.1 cfs. Restoration of the depletion of flow caused by junior priority ground water pumping would more than double the available flow to Rangen spring.

A.1. Eastern Snake Plain Aquifer Geology and Hydrogeology

The Snake River Plain is a 15,600 square mile regional aquifer system in the southern portion of Idaho. The plain exists in a graben-like feature, likely created by Middle Miocene crustal extension forces. The graben is primarily filled by Tertiary and Quaternary basalts intercalated with less extensive sedimentary rocks. Basalt deposits are made up of many thinner basalt flows (tens of feet thick) that combine to create cumulative thicknesses in excess of 1,000 feet. The eastern plain aquifer system is dominated by the Snake River Group basalt layers. Snake River Group basalt deposits are known to be up to 5,000 feet thick in some locations. (Whitehead, 1992)

The Eastern Snake Plain Aquifer (ESPA) is primarily an aquifer consisting of relatively shallow (a few hundred feet deep) and highly transmissive rubble and pillow basalts. Deeper aquifer conditions exist and are likely confined, but little data is available to evaluate them.

Sources of recharge into the aquifer include infiltration of precipitation, natural surface water losses, irrigation canal losses, deep percolation of irrigation water, recharge projects, and ground water inflow from tributary basins. Discharge out of the aquifer includes well pumping, spring discharge, ground water flow into surface water features (including the Snake River), and evapotranspiration.

Most ESPA ground water pumping occurs in the Quaternary basalts of the Snake River Group. Most wells are shallow and many can produce sustained flow rates in excess of 1,000 gallons per minute (GPM), or 2.28 cubic feet per second (CFS).

Another source of aquifer discharge is through springs in and near the canyon walls between Milner and King Hill. These springs also exhibit high flow rates and can exceed total flows of 6,000 CFS. (Whitehead, 1992)

A.2. Historical Response of Aquifer to Changing Water Use

The Eastern Snake Plain Aquifer, as outlined in Section A.1., has been described geologically as a graben filled primarily with basalt from volcanic activity throughout geologic history. The North Fork (Henry's Fork) of the Snake River enters onto the Eastern Snake Plain near the city of Ashton and the South Fork flows from Wyoming onto the ESPA at the town of Heise. Early irrigation, beginning around 1871 consisted of a myriad of canals diverting from the Snake River and tributaries and flood irrigating lands near the river (Carter, Kate, 1955 Pioneer Irrigation, Upper Snake River Valley). Early development of irrigation is documented by Stearns (1938) and later by the U.S. Geological Survey (Garrabedian, 1992). Deep percolation of irrigation water from the Snake River and tributaries began to raise water tables within the aquifer and increase discharge from the various springs issuing from the aquifer and increase the ground water reach-gain in the Snake River in hydraulically connected reaches.

Data provided by Stearns (1938) indicate that many springs issuing from the ESPA doubled in discharge between 1902 and 1917. USGS records for Curren Tunnel indicate 50 cfs in 1902 and 96 cfs in 1917 (USGS, 1958), which corresponds with the development of large irrigation projects on the ESPA. Mundorf (1964) compared early measured ground water levels in selected wells from the early 1900s to 1959 and showed that some water levels had increased between 35 and 45 feet during that period. Garrabedian (1992) estimated irrigation development for various dates during the period 1899 to 1980 indicating that major irrigation from surface sources began about 1880 and major ground water pumping for irrigation increased rapidly after 1945. The ESPA water levels rose rapidly after 1900 with some wells showing increases of 60 to 70 feet from 1902 to 1917. Spring flows, particularly on the western boundary of the aquifer (Thousand Springs area) responded to the increased aquifer water levels and began to peak about 1950. Data on continuous measured spring flows prior to 1950 are sparse; however, Kjelstrom (1986) developed an empirical procedure for estimating the total spring flow from Northside Springs which shows the general response of ESPA outflow from

1902 through 1980. This graph, Figure 2, has been updated annually by the USGS and shows that the total spring flow peaked in about 1950 and has been declining since then.

Garrabedian (1992) reported that pumping for ground water for irrigation increased rapidly after 1945 and by 1959 had reached about 400,000 acres; by 1966, 640,000 acres of Eastern Snake Plain (ESP) land were irrigated with ground water and by 1979, 930,000 acres or 40 percent of the irrigated lands on the ESP were irrigated with ground water.

Figure 3 is a graph of the cumulative discharge authorized by water rights issued by IDWR for ground water in the Eastern Snake River Plain from 1867 through 2005. A plot of the number of ground water rights issued versus the estimated Northside Spring flow (Kjelstrom) shows the relationship between estimated ground water extraction and spring response over the ESPA. The magnitude of the decline in Northside Spring flow is caused by decreases in net recharge to the ESPA caused by changes in water use, including conversion from surface irrigation to sprinkler irrigation, ground water pumping for irrigation, and, to a lesser extent, changes in climate or drought.

A.3. Rangen History of Development

Historic anecdotal evidence indicates that the Curren Tunnel was advanced into the Malad Basalt above the Rangen Research Hatchery in order to facilitate delivery of high quality spring water. Curren tunnel water was utilized for irrigation around the turn of the 20th century. Several irrigation water rights exist at the Curren Tunnel and are described in section A.4.

Rangen is one of the largest suppliers of high yield, low waste feeds for the aquaculture industry. The Rangen Research Hatchery was built in 1963 near Hagerman, Idaho for the purpose of testing experimental feed diets on a production basis. The Research Hatchery was located downstream of the Curren Tunnel ~~where the uniquely excellent spring water quality contributes to the feed research success.~~ Feed formulas are tested to assure optimum feed conversion, low mortality, high health, optimum quality, excellent growth and economy in the raising of trout. ~~The research that is performed and the trout that is produced is an important component of the success of Rangen Aquaculture.~~

A.4. Rangen Water Rights and Water Call

Rangen owns five (5) water rights with the designated point of diversion as the Rangen Spring or Martin-Curren tunnel which issues from the Eastern Snake Plain Aquifer (ESPA). Table 1 shows the Rangen water rights.

Table 1 Rangen Water Rights (Pg 2 Petition for Delivery Call Dec 13,2011)

Water Right No.	36-00134B	36-00135A	36-15501	36-02551	36-07694
Priority Date:	October 9, 1884	April 1, 1908	July 1, 1957	July 13, 1962	April 12, 1977
Beneficial Use:	Irrigation (0.09 cfs) and Domestic (0.07cfs)	Irrigation (0.05 cfs) and Domestic (0.05 cfs)	Fish Propagation	Domestic (0.10 cfs) and Fish Propagation (48.54 cfs)	Fish Propagation
Diversion Rate:	0.09 cfs	0.05 cfs	1.46 cfs	48.54 cfs	26.0 cfs
Period of Use:	Jan. 1 – Dec. 31 Domestic Feb. 15 – Nov 30 Irrigation	Jan. 1 – Dec. 31 Domestic Feb. 15 – Nov 30 Irrigation	Jan. 1 – Dec. 31	Jan. 1 – Dec. 31	Jan. 1 – Dec. 31

Rangen filed its first delivery call on September 23, 2003. Former Director Karl Dreher issued an order finding material injury to Rangen water rights 36-02551(priority July 13, 1962) and 36-07694 (priority April 12, 1977) caused by pumping by junior priority ground water irrigators on the ESPA. The Director recognized that the then current available discharge was about 10 cfs compared to the decreed water rights of 76.14 cfs. Figure 4 shows these water rights, the observed Rangen Spring flows, and the ESPAM 2.1 predicted spring flows. The Director found that there was continuing material injury to the Rangen water rights and issued an order on February 25, 2004 based on simulations of the ESPAM1.1 ground water model calling for curtailment of pumpers with priority water rights junior to July 13, 1962 in Water District 130 or for submittal of an acceptable mitigation plan for the injury. Subsequently, on May 19, 2005 the Director issued an amended order based on a re-calibrated ESPAM 1.1 model, in which he determined that the Rangen call was futile due to what was perceived uncertainty in the model based upon assumed river gauge error (+/- 10%, i.e. "trim line").

Rangen filed a request for a hearing on the May 19, 2005 order. Rangen renewed that request on June 5, 2005 and again on March 31, 2009. The Department refused to act on Rangen's repeated requests and failed to convene a hearing. Rangen submitted a new Petition for Delivery Call on December 13, 2011 which resulted in these proceedings.

B. Evaluation of Historical Availability of Water Supply at Rangen

B.1. Water Measurement Procedures and Data - Rangen Facility

Brockway Engineering PLLC (Brockway Engineering) and Leonard Rice Engineers (LRE) toured the Rangen Research Hatchery located at 2928 B South 1175 East, Hagerman, Idaho 83332 on multiple occasions. Rangen staff (Wayne Courtney, Joy Kinyon, and Dan Maxwell) and/or IDWR District 36A Water Master Frank Erwin provided tours of the Research Hatchery operations focusing on water sources and water use. Brockway Engineering and LRE photographed pertinent water features, observed standard flow measurement, and mapped water structures.

Water delivered to the Research Hatchery is supplied by the Curren Tunnel and spring water issuing from the talus slope beneath the tunnel (Figure 5). Neal Farmer of IDWR reported that the Current Tunnel elevation is 3,145 feet above mean sea level (FT AMSL), with lower elevation spring discharge in the talus slope down to approximately 3,100 FT AMSL (Farmer, 2009). Figure 6 shows that Rangen has inserted a pipeline into the tunnel for collection of ~~higher quality~~ water ~~that is not degraded by open air exposure~~ (IDWR Site ID 360410089). Rangen has also constructed a screen cover that prevents animals from getting into the tunnel. The Curren Tunnel water is piped down to the Research Hatchery building and is shown in Figure 5. Water flowing out of the Research Hatchery building is then routed either to the inlet for the 36 inch pipe or is discharged into the Lodge Pond. ~~At the time of the site visits, there was not enough flow to operate the small raceways, leaving them dry. The limited flow also dried up three of the five large raceways and one of the four "CTR" raceways.~~

Additional spring water coming out of the Curren Tunnel and in the talus below the tunnel is collected into a concrete retaining structure. The retaining structure has several pipes coming out of it, labeled as the Candy (IDWR Site ID 360410038), Musser (WMIS #410040), and Morris/Crandelmire (WMIS # 410039) pipelines in Figure 7. These pipes are associated with irrigation water rights from the Curren Tunnel. Frank Erwin indicated that the Morris/Crandelmire pipe was diverting a small amount of water as a maintenance flow that prevents pipe creep due to thermal expansion and contraction. Figure 6 shows the location of discharge of the water where approximately 50 gallons per minute (0.1 CFS) is flowing into a waste ditch on the Morris Property. Frank Erwin indicated that the Musser pipeline has been sealed and unused since the Sandy Pipeline was constructed in 2004 to use Northside Canal Company water for these irrigation rights. Since that time, the Candy pipeline has been used to water trees at approximately 70 gallons per hour (0.003 CFS) and for watering a small residential grass area once a week during the summer. Since the Sandy Pipeline was constructed in 2004, it has always met the Morris needs except for one time in 2006 when approximately 1 CFS was diverted from the Curren Tunnel for one month.

Spring water from the Curren Tunnel and a lower discharge zone flows into and around the retaining structure, cascades down a talus slope, and into a natural drainage channel that delivers water (IDWR Site ID 360410041) to the top of the large raceways identified on Figure 5. Spring discharge is diverted by Rangen using a 6-inch PVC pipe in the Curren Tunnel, a 12-inch diameter steel pipe at the retaining structure, or a 36-inch concrete pipe in the channel. These pipes can convey 3.6, 14.3, and 59.0 CFS, respectively.

Water is taken out of the channel via the concrete pipeline intake structure and is routed into the large raceways. Water flows from the large raceways through a 36-inch underground concrete pipeline to the "CTR" raceways. Each of the raceway groups has a drain which can route cleaning flows into the Lodge Pond identified on Figure 5. These drains were not operational at the time of the visit and are reportedly used infrequently.

~~It is our opinion that, at the time of the visits, there was insufficient discharge available to adequately operate the raceways and the available Rangen spring flows were being utilized appropriately and efficiently according to the adjudicated water rights (Section A.5.).~~ Flow measurement of Rangen's water rights are documented by combining the measured flow at the CTR raceways and Lodge Pond Dam locations indicated on Figure 5 (Dreyer, 2004).

During site visits LRE and Brockway Engineering observed Rangen employees collecting flow measurements. The discharge table used by Rangen employees appears to match most closely with a standard rectangular contracted weir formula with a coefficient of 3.09 rather than the typical 3.33 coefficient. This would account for the fact that the 2 inch boards over which water flows are not sharp crested, as is assumed in the standard rectangular contracted weir formula. ~~The use of a modified weir coefficient of 3.09 applied to board overflow is consistent with standard practice on aquaculture facilities.~~

Simplified weir flow calculations and a plot of the comparison of the Rangen discharge table and a standard rectangular contracted weir are presented in Appendix A along with the look up table that Rangen staff use. Review of the measurements indicates that the Rangen staff lookup tables are likely to be more accurate than the flow calculations presented in Appendix A. The standard rectangular weir discharge using a USBR weir flow calculations were within 8% of the Rangen staff reported flows. Additionally, Frank Erwin indicated that he has checked the Rangen staff measurements and that they are accurate. Furthermore, he has stated that Rangen measurements are more accurate than his own. (Deposition of Frank Erwin, Sept. 13, 2012)

B.2. Evaluation of Alternatives

Rangen has evaluated alternative points of diversion which could possibly increase the water supply necessary for operation of their Research Hatchery. Rangen evaluated the following alternatives:

1. Divert Curren Tunnel water currently used for agricultural irrigation to the Rangen facility;

2. Withdraw water from a vertical well (or wells) located at the Rangen facility;
3. Construct a horizontal well (or wells) below and near the Curren Tunnel;
4. Augment Curren Tunnel flows using water from Weatherby Springs/Hoagland Tunnel;
5. Reduce possible downward vertical flow through existing wells in the area upgradient of the Curren Tunnel;
6. Treat and re-use water from the Rangen Research Hatchery.

Rangen submitted alternatives 1-3 as grant applications to the Idaho Department of Commerce and Labor's Eastern Snake Plain Aquifer Mitigation Program. (May, Sudweeks, and Browning, 2004) The Idaho Department of Commerce approved grant funding for the first alternative of diverting Curren Tunnel water to the Rangen facility instead of for irrigation uses. However, this grant funding was never needed or used because conveyance structures were built to deliver Sandy Pipeline water to the Candy property for irrigation use on lands previously irrigated by Curren Tunnel water.

Alternative 2 explores the possibility of using vertical wells to pump water from locations below the canyon rim at the Rangen facility. The geologic evidence supports current theories that the Curren Tunnel water is flowing through pillow basalts overlaying less permeable sediments. Any viable vertical well location would have to provide a sufficient quantity and quality of water from a source that would not further deplete the Curren Tunnel flows, or that is not currently collected by Rangen. The upgradient geology above the Rangen facility effectively funnels the ~~high quality spring~~ water to Rangen's collection points at the tunnel, the retaining structure below the tunnel, and at the pipe intake further down in the Billingsley Creek channel. Possible well locations with sufficient water quantity ~~and quality~~ would likely reduce the flow of water to the Curren Tunnel, or the spring flow in the talus slopes below. The other possible well locations would likely encounter less permeable sedimentary deposits with lower well yields, unsaturated basalts, or reduced water quality affected by overlying agricultural land use. Any location for possible vertical well drilling that isn't providing water to the current Rangen collection locations is unlikely to provide the quantity ~~and quality~~ of water necessary to make this a feasible option for an alternative point of diversion.

Alternative 3 evaluates the possibility of drilling a horizontal well below the Curren Tunnel. This alternative is subject to the same requirements listed above. A horizontal well must access water of sufficient ~~quality and~~ quantity that is not already available to Rangen. The geologic evidence and field observations show that ground water flow in the area above Rangen is discharging primarily at the Curren Tunnel and the talus below. Any water flow not coming to the Curren Tunnel discharges into the talus slopes below and is collected by Rangen's lower intake structure in the Billingsley Creek drainage. While a new horizontal well might increase flow at the Curren Tunnel location, it would reduce flow to the lower talus discharge area and it is therefore unlikely that it would increase flow to the Rangen facility. Furthermore, a horizontal well has the potential to injure the other Curren Tunnel water rights by drying up the tunnel flows (Erwin, 2012). A horizontal well alternative is not a feasible option for these reasons.

Alternative 4 assesses the possibility of piping water from the Hoagland Tunnel to the Rangen Research Hatchery. Rangen has researched this alternative and determined that only 0.7 CFS would be physically available for seasonal, inconsistent delivery to the Rangen facility. The expense of delivering this water to the Rangen Research Hatchery would be high. The water from the Hoagland Tunnel has been fully appropriated and would not be legally available for transfer to the Rangen Research Hatchery. For these reasons, an alternative that utilizes Hoagland Tunnel water at the Research Hatchery is not feasible.

Alternative 5 suggests investigation of a theory that shallow aquifer water is being moved deeper into the aquifer, or into a deeper aquifer, by downward gradients in existing wells. This is unlikely to show a significant impact on the Rangen Spring flows. A constant flow of water through wells deeper into the aquifer, or into deeper aquifers, is highly unlikely to be of a magnitude greater than that of the pumping out of the aquifer for irrigation use. The primary flow of water is horizontally through the aquifer. Seasonal variability in the aquifer water levels, pumping patterns, and spring flow are all correlated and discussed in Section E below.

Alternative 6 presents the idea of pumping back used water from below the Rangen Research Hatchery back up to the research building and raceways. This would require ~~significant treatment of the water,~~ redundant power systems, and could injure downstream senior water rights. Rangen's use of water has historically been non-consumptive and a sustainable pumpback system ~~with sufficient water treatment~~ would likely be an expensive system with some amount of water consumption.

~~It is our opinion that the current Rangen Research Hatchery diversion structures are reasonable and that they fully utilize available water to Rangen's water rights. The diversion structures are consistent with the industry standard for aquaculture facilities in the Magic Valley. Based upon our knowledge of other area facilities, the Rangen Research Hatchery is consistent with the industry standard of practice for conservation and beneficial use of available water and does not waste diverted water.~~ Rangen has made significant efforts, and yet no alternative method of water diversion has been identified that would provide the Rangen facility additional water with a viable quantity ~~and quality~~ that isn't already being accessed by existing diversion structures.

C. ESPAM 2.1

C.1. ESPAM Development History

Initial ground water modeling of the Eastern Snake Plain Aquifer was performed by the U.S. Geological Survey (USGS) who built an analogue model of the aquifer in 1960's. This model was a research tool and, as with all hard-wired analogue models, was difficult to operate. The need for better analytical procedures for aquifer/Snake River relationship became evident in the early 1970's when IDWR was evaluating and planning for the first State Water Plan. The Idaho

Technical Committee on Hydrology (ITCH) conducted a water resources needs assessment in 1988 and identified an Eastern Snake Plain Aquifer ground water model update as a priority.

IDWR contracted with the University of Idaho Water Resources Research Institute (IWRRI) to develop a digital model of the ESPA aquifer. This effort was conducted at the University of Idaho Kimberly Research Center. The model was developed by a Civil Engineering graduate student from the Netherlands, Jos de Sonneville. The model code was a finite difference, non-proprietary code with cumbersome data management routines. This model was utilized by IDWR to better understand the aquifer responses to changes in water use and was manually calibrated. Subsequent additions and changes were made to this model, primarily by graduate students at the University of Idaho.

In 1999, the model code was converted to the USGS MODFLOW code since it was non-proprietary, supported by the USGS, and had been utilized on a significant number of modeling projects. This work was performed by IWRRI under the direction of Gary Johnson. Subsequently IDWR embarked on a major upgrade of the ground water model with funding assistance from various entities including canal companies. The upgrade was contracted to IWRRI and resulted in ESPAM 1.1 in 2004 which was calibrated with an automated calibration routine and was utilized both for planning purposes and for conjunctive administration. ESPAM 1.1 was re-calibrated in late 2004 and used by IDWR until another upgrade was initiated to improve the resolution of the model grid, revise input data and management routines, and improve calibration utilizing individual historical measured spring flows. This upgrade, ESPAM 2.0, was recommended by the ESHMC and adopted by IDWR in July 2012. The ESHMC recognized the improvements to the prior model and recommended that IDWR begin using ESPAM 2.0 instead of ESPAM 1.1.

In October 2012, a water balance mistake was found in the model inputs for Mud Lake. IDWR presented information regarding the mistake and the revised calibration results for model E121025A001 in the November 9th, 2012 ESHMC meeting. Since then, IDWR has accepted model E121025A001 as ESPAM 2.1. IDWR has provided ESPAM 2.1 calibration results, steady state response functions, a superposition model, curtailment scenarios, validation model runs, and is currently working on an analysis of predictive uncertainty. None of these exercises indicate that there is substantive difference regarding the comparison of ESPAM 2.0 to ESPAM 2.1 predictions for the Rangen spring. Director Spackman has indicated that ESPAM 2.1 is now being used for ground water modeling by IDWR and that it will be used to evaluate the Rangen call. (Rick Raymondi email to ESHMC dated November 27, 2012)

C.2. IDWR Procedure for Determining Individual Spring Flow

The Department has the responsibility to evaluate material injury to senior water rights and to use the "best science available" when analyzing the impacts or interference caused by out of priority water rights. An advisory committee to IDWR, the Eastern Snake Hydrologic Modeling Committee (ESHMC), contributed to the ESPAM update and reviewed the procedure and final model. The ESPAM 2.1 ground water model was adopted after a satisfactory calibration, validation, and comparison with the output from the ESPAM 1.1 model as requested by the Director of IDWR.

Brockway Engineering used the ESPAM 2.1 ground water model and IDWR curtailment methodology to simulate the impact of junior priority ground water rights to the latest Rangen priority water right (April 13, 1977) and July 12, 1962 for the Research Hatchery. The procedure used the calibrated ESPAM 2.1 model to simulate the steady state change in individual spring flows, Snake River reach gains and aquifer water levels attributable to aquifer depletion changes. Utilization of a ground water model in the superposition mode to simulate change in an output variable caused by changes in depletion within the aquifer is implicitly more certain than modeling differences in the simulation of the absolute value of the output with a fully populated model. IDWR saves computing time by using the superposition version of ESPAM 2.1 to evaluate changes in spring flows due to curtailment instead of the fully populated model. The superposition mode requires only that differences in recharge or depletion be input at specific locations within the model and not the entire input data set. The simulated differences using this method eliminates the need to run the fully populated model twice to determine the simulated impact of changes in specific input.

The evaluation of the depletive impact to the springs relied upon Rangen, utilizing the above IDWR procedure and the ESPAM 2.1 ground water model, shows an impact from curtailment of ground water pumping within the area of the model under water rights junior to July 13, 1962 of 17.9 CFS at steady state. It is estimated using the transient ESPAM 2.0 model that a recovery to 90% of the steady state value (16 cfs) will occur within approximately15 years.

C.3. ESPAM 2.1 Calibration

IDWR used PEST (Doherty, 2005) automated calibration software to calibrate ESPAM 2.1. Model calibration is the process of comparing actual observations with model output or predictions and adjusting the model input parameters until the error between observations and modeled predictions is minimized. A model is well calibrated if the model output closely matches what is observed in historic time series data sets. The quality of the overall model calibration depends on the quantity, location, time, and type (water level, flow, aquifer property) of observations compared to model results. Model calibration quality varies spatially and temporally and is improved in those locations where observation data are available.

Adjustable input parameters used during ESPAM 2.1 calibration include aquifer transmissivity, aquifer storage coefficients, river bed conductance, drain conductance, non-irrigation recharge, evapotranspiration on surface water irrigated land, non-snake river seepage, tributary valley underflow, canal seepage, deep percolation, and soil moisture.

Calibration targets are real world observations used to compare to model predictions. The selection and development of calibration targets reflects the intended predictive capacity of the model. ESPAM 2.1 calibration targets include river reach gains, spring flows, aquifer water levels, base flow, and irrigation return flows.

The difference between each model prediction and calibration target is called a residual. During calibration, PEST attempts to minimize these residuals and reports a sum of squared residuals, also called the objective function or phi. The objective function value is a primary measure of calibration quality and is used by modelers throughout the calibration process.

IDWR calibrated ESPAM 2.1 by starting with a steady state stress period consisting of average model inputs. A transient "warm up period" follows from May, 1980 through April, 1985, where no calibration is attempted. Transient model calibration occurs from May, 1985 through September, 2008. Calibration is an iterative process, and IDWR developed several calibration runs. The calibration of the ESPAM 2.1 model and validation procedures were reviewed by the ESHMC and comparisons of simulated historical individual spring discharge data sets were compared with model-simulated output. In the November 9, 2012 meeting, ESHMC accepted calibration run E121025A001 as the final ESPAM 2.1 calibration run.

Based on the approved, calibrated model and the performance of the model in simulating individual spring historical flows, the ESPAM 2.1 model is capable of simulating impacts on individual springs, including the Rangen spring. It is our opinion that the ESPAM 2.1 model is the 'best science available' to evaluate impacts on spring flows caused by pumping junior ground water rights in the ESPA..

ESPAM 2.1 utilizes the MODFLOW Drain Package to represent 90 spring discharges from the aquifer in the Snake River Canyon between Kimberly and King Hill. The main input components of the Drain package include the elevation and hydraulic conductivity of the drain. IDWR and ESHMC separated springs into groups A, B, and C. Group A springs have flows measured and reported by the USGS or IDWR. Group B springs are measured and reported by water users. Group C springs are all of the other springs in the model that have less reliable historic flow measurement data.

In the Thousand Springs area of the Snake River, selected springs with adequate measured historical discharge data were utilized as targets in the calibration process to which simulated output was matched as closely as possible by allowing PEST to adjust the internal parameters of the model such as hydraulic conductivity, storativity, target spring coefficients, target spring elevations, and external input parameters. Examples of the use of target springs are shown in Appendix B, which contains IDWR calibration graphs of the measured discharges at the select springs versus the simulated output of the ESPAM 2.1 model for the same period. Appendix B model comparisons of simulated and measured spring flow shows the simulated discharge at springs versus historical measured discharge for the ESPAM 2.1 calibration. This close "fit" indicates the model, if calibrated properly, is capable of simulating the historical spring discharge from the model cell(s) representing the Blue Lakes springs. Similarly, the ESPAM 2.1 simulated output versus measured for the calibration period for Box Canyon Spring and all other spring targets are included in Appendix B.

Other springs in the Thousand Springs area of the Snake River (Milner to King Hill) were used as targets in the ESPAM 2.1 model calibration. They were designated as Class B and Class C springs and were chosen on the basis of adequate discharge measurements over the period of calibrations. Some of these springs were: Briggs Spring, Clear Lake Springs, Devils Washbowl, Devil's Corral, Thousand Springs, Rangen Spring, and Malad Gorge. Historical measured discharge of the Rangen Spring was also used as a calibration target for the ESPAM 2.1 ground water model calibration. The discharge measurements for Rangen Spring were submitted to IDWR by Rangen and included measurements from May, 1980 through October, 2008.

Use of the ESPAM 2.1 model as currently calibrated for simulation of impacts from junior ground water pumping is the "best science available" in our opinion. The Rangen Spring is the only spring in its' model cell (Row 42, Column 13). It has a long historical record of flow observations that were used as targets and resulted in a high quality calibration. IDWR's current update of the ESPAM model to ESPAM 2.1 improves the calibration input parameters credibility, and improves the procedures for crop evapotranspiration determination and distribution of irrigation sources. It also corrects some previous oversights in target spring flow determinations.

C.4. Use of Historical Rangen Spring Flow Data for Calibration

Prior versions of ESPAM did not represent the Rangen Spring as an individual spring. The impact on Rangen Spring was represented as a fixed percentage of river gains in the Thousand Springs to Malad reach of the Snake River as a result of changes in ground water pumping or other depletion changes in the aquifer. ESPAM 1.1 was calibrated to match the calculated gains in each Snake River reach and also to match some of the major springs. Rangen Spring, and the remaining springs, were represented as percentages of river gains based on the published Covington and Weaver spring flow estimates. This approach to spring flow estimates is problematic because the Covington and Weaver estimates had not been substantiated. Furthermore, the magnitude and responses of river gains and spring flows are not similar and should not be grouped together

With contributions of work from IDWR and also individual ESHMC member stake-holders including Rangen, many more historical spring flow time series were calculated, reviewed and accepted by the ESHMC, and made available to the IDWR ESPAM modelers. Therefore in ESPAM 2.1, the calibration targets were expanded to include many more individual spring flows, reducing the calibration reliance on river reach gains calculations where possible. The improvement in the ESPAM 2.1 calibration and individual spring flow simulation performance was remarkable.

The evaluation of historical Rangen spring flows was presented by LRE (Jim Brannon) in the September, 2009 ESHMC meeting. These data, and historic flow data for other springs were approved by the ESHMC for IDWR use in calibrating the ESPAM 2.1 model. The historic Rangen spring flow data are shown in Figures 4 and 9.

C.5. Analysis of Rangen Spring Calibration Results

The Rangen Spring is a group B spring represented as a single drain set at an elevation of 3,138 feet. The drain hydraulic conductivity is an adjustable parameter that is estimated during the calibration process (see Section C.3., above). There are no other springs represented in the Rangen cell.

Figure 9 shows the E121025A001 (ESPAM 2.1) calibration results distributed by IDWR for the Rangen Spring. The top graph shows the measured and modeled spring flow from May, 1980 through September, 2008. There are multiple scales of patterns that emerge when reviewing the graph qualitatively. The longest pattern evident is a long term (multi-decadal) linear decrease in spring flows. The 1981 measured and modeled spring flows average approximately 32 and 30 CFS, respectively. The measured and modeled spring flows decrease to an average of approximately 14 and 19 CFS, respectively, in 2008. Through the 1980-2008 model run, the mean error is reported as 0.04 CFS with a mean absolute error of 4.57 CFS. The signal (prediction magnitude) to noise (error) ratio decreases as the spring flow decreases. However, the long term drop in average spring flow is modeled accurately by ESPAM 2.1 and indicates that the model is representing long term impacts to the spring flow. These impacts reflect well pumping changes, climate changes, and changes in irrigation practices.

Figure 9 shows a decadal scale, sinusoidal trend in observed spring flow that is matched well by the modeled spring flow predictions. Both data sets show decadal scale highs in 1987 and then again in 1998. The measured and modeled spring flows also show decadal scale lows in 1993 and 2005. The model matching these spring flow changes indicates that decadal scale impacts from changes in climate and irrigation practices are being accurately modeled.

Figure 9 also shows an annual seasonal and pumping-impacted variation in measured and modeled spring flows. In general, the model accurately represents both the magnitude and timing of seasonal and pumping-impacted spring flow fluctuations. This is represented in the lower-center graph showing Average Monthly Spring Flow. The top graph shows seasonal measured versus modeled spring flow matches are better earlier in the calibration model run when average spring flow is higher and the seasonal magnitude of change is greater. This is another expression of the model signal to noise analogy discussed above. The seasonal variations in the spring flows are attributable to seasonal pumping and are accurately represented by the model.

The lower right graph on Figure 9 is a scatter plot showing modeled versus measured spring flow. These data remove the element of time from the evaluation and show the overall quality of modeled predictions compared to measured spring flows. The trendline of the scatter plot shows a coefficient of determination, or R-squared value, of 0.75. A perfect match would be a value of 1.0. The R-squared value is diminished by the quality of fit below 20 CFS on the modeled spring flow axis. This is another expression of the model having less accurate low flow predictions, as discussed above. Appendix B includes similar plots of ESPAM 2.1 calibration simulations compared to measured flows for Box Canyon, Crystal Springs, and Blue Lakes Spring with the same statistical parameters as shown in Figure 9 for Rangen Spring. The calibration or 'fit' for these springs shows that the ESPAM 2.1 model is well calibrated and adequately simulates the historical responses of the calibration target springs.

IDWR has stated in their ESPAM 2.1 final report that," Unlike ESPAM 1.1, ESPAM 2.1 was calibrated to the discharge of 14 springs, and spring cells without transient targets were calibrated using a ranking scheme, see section VI.C. Thus ESPAM 2.1 can be used to compute regional impacts on selected springs" (IDWR 2012). It is our opinion that the ESPAM 2.1 calibration quality at the Rangen Spring and other major springs is an indication that the model is an excellent predictor of long term individual spring flow changes and decadal spring flow changes. The Rangen Spring is one of the best points of prediction for the ESPAM 2.1 model because it was a calibration target, it is the only spring in the model cell, and it has excellent calibration results.

C.6. Evaluation of IDWR Analysis of Uncertainty, Validation and Comparison to 1.1

In a letter to the ESHMC dated June 9, 2011, then Interim Director Gary Spackman indicated that before ESPAM 2 could be used for water management and administration, the model must undergo a series of quality evaluations.

> *"In order to accomplish the foregoing, I have instructed IDWR technical staff to subject ESPAM 2.0 to rigorous testing, including: 1) calibration; 2) validation; and, 3) uncertainty analysis. In addition, ESPAM 2.0 must be run using factual inputs and additional hypothetical factual inputs. Simulations from these inputs must be compared with the outcomes of the previous model version."*

In an effort to comply with the Director's request, and in some cases improve the model, IDWR performed uncertainty, validation, and comparison to ESPAM 1.1 exercises.

C.6.1. Uncertainty

IDWR utilized the "dual calibration" predictive analysis mode of PEST software (Doherty, 2005) as a tool to explore predictive uncertainty in the model. "A comprehensive predictive uncertainty analysis could not be conducted in a reasonable timeframe, so the ESHMC chose to conduct a maximization/minimization uncertainty analysis. In lieu of a probability distribution, the maximization/minimization analysis provides upper and lower bounds for the probability distribution, with output from the ESHMC-chosen calibrated model supplying the most likely outcome. (IDWR Wylie 2012a)

This method relies on the modeler to induce a large stress on the aquifer at a distance from a prediction, and then PEST determines the minimum and maximum prediction values of specific output possible while keeping the model calibrated. The current IDWR uncertainty analysis procedure relies on allowing models to have a larger objective function, or worse calibration, and still be considered calibrated. Because of this, the original calibration model still provides the best predictions. This method of uncertainty analysis is useful in determining what parameters are well constrained by the observation data. It does show that utilizing models with different calibrations provide differing ranges of output of predictive values for specific output locations (specific springs or reach gains). However, there is no uniform range of output predictions at all locations and specifying a single uncertainty value to the entire model is not technically valid. It does show that utilizing models with different calibrations provide differing ranges of output of predictive values for specific output locations (specific springs or reach gains). However, there is no uniform range of output predictions at all locations and specifying a single uncertainty value to the entire model is not technically valid. It also provides information about the spatial variability in parameter uncertainty, and what impact that can have on predictions. The uncertainty results distributed by IDWR are valuable in guiding future data collection activities that will improve upon ESPAM 2.1. ;however, at this point, a complete uncertainty analysis has not been performed that can appropriately be used to apply a confidence interval range or probability distribution on the predictions of ESPAM 2.1. The best estimate of the impact on a spring or river reach by any change in depletion (pumping or recharge or other changes) is the unmodified prediction from the ESPAM 2.1 model. Any other result using the current model is statistically less probable and would be inappropriate to use.

Ground water models can and are regularly used without performing a comprehensive uncertainty analysis. Depending on the nature of the use of the model, availability of data for verification, computing facilities and time constraints and the modeling entity experience, comprehensive uncertainty analysis may or may not be performed. It is common in the industry to utilize a ground water model without validation or extensive uncertainty analysis. The model output should be the most reliable values and any modification of the output to qualify the results based on limited or no statistically evaluated procedures is not warranted.

In summary, our opinion is that the current uncertainty analysis has no bearing on the model predictions. Any output value other than the specific model output will provide a lower confidence level or more uncertainty because it results from a model with a less stringent calibration than the base model.

Although the limited uncertainty analysis performed by IDWR is useful in understanding some aspects of the model, it cannot be used to technically justify any range of model predictive results. A complete uncertainty analysis has not been performed that can appropriately be used to apply a confidence interval range or probability distribution on the predictions of ESPAM 2.1. The best available predictions of junior pumping impacts to the Rangen Spring are those made by calibrated model E121025A001 (ESPAM 2.1).

C.6.2. Validation

Validation is an attempt to demonstrate a calibrated model's performance for a period of time outside the calibration period. The comparison period(s) must have independent observation data to which the modeled predictions can be compared. The result of a model validation assessment will not be validation of the model. Rather, the result of this assessment would only be to invalidate the model, or not invalidate the model.

ESPAM 2.1 validation was performed by using the accepted, calibrated model (E121025A001) to evaluate a two year period (2009-2010) after the calibration period (1985-2008). Another validation run was performed with ESPAM2.1for 1900 model inputs.

C.6.2.1. 2009-2010 Validation

IDWR contracted a statistician, Maxine Dakines, Ph.D., to develop statistical measures for evaluation of the validation results. Two of the measures she recommended using were the Root Mean Squared Error (RMSE) and the Median Absolute Deviation (MAD) (Dakines, 2012). These measures were applied to the 2009-2010 validation run results and the ESPAM 2.1 calibrated model.

Validation statistical results were within the range of calibration statistical analysis results except for the weighted spring discharge results. These results indicated that ESPAM 2.1 had a tendency to over predict spring discharges, which is consistent with review of the model calibration results

C.6.2.2. 1900 Validation

The 1900 validation run was based on input data and observation data from rough estimates and historic documents that are much less reliable than the calibration period data and the 2009-2010 validation data. For this reason, ESHMC members and IDWR agreed that the 1900 validation run was less significant. The nature of the 1900 data available precluded a statistical analysis of the results, and so only a qualitative description was provided by IDWR. IDWR concluded, and we agree, that the 1900 validation results do not limit the use of the model in any way (IDWR Wylie 2012b).

C.6.3. Summary-Validation

IDWR's conclusion presented in their ESPAM 2.1 validation report (IDWR Wylie 2012b) stated that calibration results for ESPAM 2.1indicate that the validation evaluation raised no "*significant concerns or limitation regarding the use of ESPAM 2.1.*" We agree with the IDWR conclusion and it is our opinion that these validation results further support the use of ESPAM 2.1 as the best available science

C.6.4. Comparison of ESPAM 2.1 to ESPAM 1.1

IDWR completed a comparison of ESPAM 2.1 to the previous version used for administration, ESPAM 1.1. The procedure they implemented included a comparison of ESPAM 2.0 to 1.1 while being run as transient, fully populated and superposition models. This test was performed to determine if the simplified superposition model was accurate enough to complete curtailment scenarios. The superposition model predictions were less than 1% different from the transient, fully populated model. The superposition model was sufficiently accurate and so was used for each of the curtailment runs because it required fewer data, decreased computing time, and simplified the process.

IDWR used ESPAM 2.1 to run curtailment scenarios using five priority dates and where run as steady state models, 150 year transient models with average annual, and 10 year continuous curtailment models with seasonal average stresses. The process representing curtailment of junior well pumping is complicated by the relationships between real world well pumping, water rights databases, and the way well pumping is represented in the model. A detailed discussion of these issues follows in the next section.

Improvement in the estimates of model input and calibration target data for version ESPAM2.1 resulted in the consumptive use curtailed using ESPAM 2.1 being 17-21% higher than with ESPAM 1.1. This is generally attributed to increased confidence in model inputs and calibration targets, and their contribution to increased confidence in model output.

C.7. Using ESPAM 2.1 to Simulate Impacts of Well Pumping Curtailments

With the successful calibration to the historical period data, the next phase of ESPAM 2.1 model use is to simulate responses of the aquifer system to conditions representing scenarios of interest to stake-holders in the basin. One common administrative water rights scenario of interest to many in the basin is the impact that curtailment of pumping and/or aquifer recharge projects would have on spring flows and reach gains.

C.7.1 2011 LRE method

In late 2011, as ESPAM 2.0 was nearing its final calibration, LRE began using the available version of the ESPAM 2.0 model and the IDWR POD and POU water rights databases to simulate the impacts of pumping curtailment, especially on the Rangen spring. The objective was to obtain a general understanding of the hydrologic and hydraulic behavior of the systems as represented in the ESPAM model and data, and anticipate the spring flow responses to a pumping curtailment caused by a water right call with the Rangen priority date (July 13, 1962). These analyses have been superseded by IDWR work and are not being relied upon except as an independent, qualitative comparison of the appropriateness of the IDWR curtailment methodology.

Because the Rangen spring historical flows are explicit calibration targets, ESPAM 2.1 has proven to be an excellent model of the East Snake Plain Aquifer and Rangen spring flows. The pumping curtailment scenario is well within the ESPAM 2.1 historical model "state space" used during calibration, as the reduction in pumping would return water levels (and therefore spring flows) to values that are still well inside the historically observed range.

LRE (independently from IDWR) developed a spatial and logical algorithm using the IDWR 2011 POD and POU water rights databases that resulted in junior and senior water rights fraction values per ESPAM model cell based on a certain calling priority date. This algorithm was designed to handle the foreseen major water rights data management issues and also to be conservative in nature when water rights data was unclear or in error. These fractions were then used to adjust the ground water acreage values in the ESPAM 2.0 IAR files used by the MKMOD utility (MODFLOW data pre-processor). The MKMOD and MODFLOW programs were then rerun with the modified data and the model output (river reach gains, spring flows, etc.) compared to determine pumping curtailment impacts.

C.7.2 2012 IDWR method

During 2011 and 2012 IDWR created a set of data pre-processing tools based within the ESRI ArcGIS environment. One of the features completed during 2012 was a "pumping curtailment scenario" data creation tool.

The IDWR tool is also based on POD database data, but used a different algorithm. Rather than adjust an existing IAR file, it recreates the irrigated acreage data (and IAR file) from scratch using the base ESPAM 2.1 spatial and temporal data. It also includes additional refinements to the underlying data (such as ground water vs. surface water irrigated percentages) to improve the accuracy.

C.7.3 Comparison of LRE and IDWR Curtailment Scenario Results

When the IDWR tool became available, LRE acquired it and the necessary IDWR data. An ESPAM 2.0 pumping curtailment scenario identical to the previously developed scenario (using the LRE approach) was constructed and run through the ESPAM 2.0 model. The results showed excellent agreement, even though the systems were developed independently. The excellent agreement verified LRE's earlier estimates of pumping curtailment spring flow impacts, and is an encouraging indicator of the robustness of the IDWR curtailment tools. Brockway Engineering also completed simulations with the calibrated ESPAM 2.1 model and the IDWR algorithms for determining curtailment priority locations, which duplicated the IDWR process and results.

It is our opinion that the IDWR curtailment methodology is an accurate evaluation of impacts caused by junior ground water pumping and that it provides accurate input for the ESPAM 2.1 model.

D. Benefits from Curtailment for Rangen Call

Evaluation of the benefits of curtailment of ground water rights junior to July 13, 1962 results in increases in Rangen Spring of approximately 17.9 cfs average annual flow at steady state. This evaluation was performed using the ESPAM 2.1 ground water model assuming curtailment to July 13, 1962, over the entire aquifer.

~~Utilization of the increased spring discharge within the Rangen Research Hatchery will allow increased fish production as well as rehabilitation of research facilities and historical fish propagation research.~~ Additional benefits would also be realized by hundreds of water rights downstream of the Rangen Research Hatchery in the Billingsley Creek water rights system. (Erwin, 2012)

The Idaho Comprehensive Aquifer Management Plan and State Water Plan call for an additional 600,000 acre-feet per year of water to be returned to the ESPA. Curtailment to effect mitigation for historical decreases in Rangen Spring results in significant increases in discharge at other developed springs and benefits to water rights holders who utilize the increased discharge for irrigation or other uses. Table 2 shows the results of the ESPAM 2.1 curtailment scenario on Snake River reach-gain and the A, B, and C springs designated by IDWR as calibration targets in the ESPAM 2.1 development. Most of these springs are either fully developed for aquaculture purposes or have some non-aquacultural development. For instance, the Rangen Spring discharge, after the non-consumptive use for aquaculture by Rangen Inc, serves as the source of irrigation for water rights on Billingsley Creek, other fish producers, and canals diverting from the Creek. Increases in Malad springs benefit Idaho Power hydroelectric facilities and increases in Blue Lakes spring benefit two major fish hatcheries (Blue Lakes Trout and Pristine Springs), as well as the City of Twin Falls municipal water supply.

Similarly, increases in Upper Snake River reach-gains as a result of ground water pumping curtailment for Rangen Inc, benefit irrigators with senior water rights as well as fish producers utilizing spring water.

Table 2 shows that a total of 1,679 cfs (or 1.22 million acre feet annually) of enhanced Upper Snake River reach gain and flow in the A, B, and C springs in the Thousand Springs area will accrue from ground water pumping curtailment for the Rangen Spring. Increases of 389 cfs or 282,200 acre feet per year in the flow of named A, B, and C springs only will accrue from ground water pumping curtailment for the Rangen Spring. These increases represent only the target calibration springs which are the larger springs in the reach from Minidoka to King Hill. Other springs in the area which were not selected as target springs for ground water model calibration have some degree of development and benefit from increased discharge.

Snake River reach-gain increases as a result of curtailment for the Rangen Spring and those reach gains are beneficial for stabilizing existing water supplies for irrigation, for in-stream beneficial uses, including hydropower production increases. ~~Reach-gains increase throughout the entire year, provide beneficial uses outside the irrigation season for water quality and fisheries enhancement.~~

Water levels within the ESPA will increase as a result of curtailment of junior ground water pumping. Simulation with ESPAM 2.1 of curtailment to July 13, 1962 priority water rights results in significant increases in water levels within the aquifer. It is estimated that full aquifer curtailment results in a decrease in ESPA depletion of 1,456,405 acre feet per year(AFA). The same simulation indicates that the average water level increase over the ESPA as a result of this curtailment may be as much as 24 feet.

Table 2: Simulated River Reach/Spring Gain (ESPAM 2.1) from curtailment on entire ESPA with water rights junior to 7/13/1962

River Reach	Gain (CFD)cubic feet/day	Gain (CFS)	Gain (AFA)
Ashton - Rexburg	13,632,890	158	114,312
Heise to Shelley	17,841,178	206	149,598
Shelley to Near Blackfoot	19,837,276	230	166,335
Near Blackfoot to Minidoka	60,067,316	695	503,664

Specific Spring	Spring Class	Gain (CFD)	Gain (CFS)	Gain (AFA)
BANBURY	C	284,855	3.3	2,389
BANCROFT	C	59,840	0.7	502
BIGSP	C	612,377	7.1	5,135
BIRCH	C	5,764	0.1	48
BLUELK	B	1,729,410	20.0	14,501
BOX	A	5,939,274	68.7	49,801
BRIGGS	A	98,073	1.1	822
CLEARLK	B	3,614,815	41.8	30,310
CRYSTAL	B	3,952,452	45.7	33,141
DEVILC	A	638,568	7.4	5,354
DEVILW	A	489,835	5.7	4,107
ELLISON	C	9,951	0.1	83
MALAD	B	3,797,106	43.9	31,839
NIAGARA	B	2,762,952	32.0	23,167
NTLFSHH	B	982,322	11.4	8,237
RANGEN	B	1,545,320	17.9	12,957
SAND	B	1,583,856	18.3	13,281
THOUSAND	B	4,325,425	50.1	36,269
THREESP	B	1,125,718	13.0	9,439
TUCKER	C	97,535	1.1	818
Total		**33,655,448**	**389**	**282,200**
Total Springs Below Milner		**145,034,108**	**1,679**	**1,216,109**

E. Alternative Procedures to Estimate Spring Discharges

E.1. Individual Spring Simulation with ESPAM 2.1 Model

The primary hydraulic parameter affecting spring discharge is the water level in the aquifer immediately up-gradient from the spring outlet. The spring orifice or outlet acts like a weir in an open channel where discharge is a function of the head or water level difference between the weir crest and the upstream pool water level. The MODFLOW code for the ESPAM model incorporates an algorithm for treatment of spring outflow called the Drain Module (McDonald and Harbaugh, 1988) where the relationship between spring discharge and aquifer water level is given by;

$$Qd = Cd(h-d)$$

where

- Qd = spring discharge or flow to a drain
- Cd = drain conductance constant value
- h = head(elevation of water level) in the aquifer
- d = elevation of the drain(weir crest)

This equation is a linear equation which assumes that the coefficient Cd does not change with elevation and that the discharge changes proportionately with the change in aquifer water level(h) compared to the spring elevation. McDonald and Harbaugh (1988) indicate that the constant drain conductance incorporates converging flow lines, aquifer hydraulic conductivity and other hydraulic considerations of the spring geology. The drain module equation shows the dependence on an accurate determination of spring elevation in correctly modeling the response of a spring to water level elevations in the aquifer. The drain parameters are adjusted by the automatic calibration routine, PEST.

E.2. Method 2: Regression of Spring Discharge vs. Aquifer Water Levels

The algorithm which is used to simulate spring flow in ESPAM 2.1 is essentially a form of weir equation for which the operating variable is water surface elevation up-gradient of the drain cell. Therefore, the expected response of the spring discharge must be related to changes in up-gradient water levels. With this as the hypothesis, the relationship between target spring flow versus historical measured water levels in wells up-gradient of the spring should be relatively well defined. If that is the case, the relationships developed by regression methods using historical measured water levels and measured spring flows should be adequate for estimating the spring discharge response.

There are several wells within the ESPA which are adjacent to and up-gradient of target springs in the Milner-King Hill reach of the Snake River. These wells have records of measured water levels with as much as 60 years of data and measured discharge at target springs began as early as 1950. Well data are available online from IDWR through Hydro.Online (http://www.idwr.idaho.gov/hydro.online/gwl/default.html).

As an example, to evaluate the relationship between up-gradient ground water levels and Rangen Spring flows, a correlation was performed between historical water levels in observation wells 06S13E25DBC1, 07S14E29CDC1, 07S15E12CBA4, 08S14E12CBC1,08S14E16CBB1, 08S15E32CBB1,and 08S16E17CCC1 which are up-gradient of the Rangen Spring (Appendix C) and measured discharge from the Rangen Spring.

The data set used included measured discharge and corresponding measured water levels in the well for the period of record for the observation wells. Appendix C contains figures that show the correlation between aquifer water level and discharge with a correlation coefficient. For example, observation well located at 07S15E12CBA4 has a correlation coefficient, C, of 0.8851; this coefficient indicates that over 88% of the variability in Rangen Spring discharge can be explained by the water level variability in a predictor well. Table 3 shows the regression data for the seven wells with Rangen Spring and the average regression fit to measured discharge for the wells.

This analysis corroborates the procedure of using a regression approach to estimating spring discharge. Further, it supports the current procedure for inclusion of Rangen Spring in the ESPA model and that the flow at Rangen Spring is from the regional aquifer. In addition, the well to spring regression procedure eliminates the concern of inaccurate drain elevations at springs and provides a statistically defensible confidence level to the estimate if the water level change is known.

Analyses and data evaluated by Koreny (2009) and previous work by Janzak (2001) and HRS (2007) suggested that relationships between water levels in the ESPA and spring flows might be developed with sufficient reliability to be utilized as alternative methods to estimate benefits to spring flows from curtailment of junior ground water pumpers. Dr. Wylie's testimony at hearing also supported such review and recommended that additional analysis would be necessary.(Deposition of Allan Haines Wylie, PhD. November 13, 2009, p51)

The physical justification and methodology of developing the regression relationships is outlined in detail in Appendix C. The conclusion of the investigation into utilization of aquifer level vs. spring discharge correlation is that the regression with observation wells is a justifiable alternative procedure to ESPAM 2.1 simulation to evaluate Rangen Spring discharge and provided additional validity to the use of ESPAM 2.1 for individual spring impact predictions.

F. Summary of Opinions

This report presents the opinions of Jim Brannon, Chuck Brockway, and Dave Colvin regarding the evaluation of impacts by junior pumpers to Rangen's water rights, the application of these impacts to a determination of injury, and the appropriate use of the ESPAM 2.1 model. These opinions are couched to address the requirements contained in the Conjunctive Management rules.

In summary, our opinions are as follows:

1. Pumping by junior ground water rights impacts the exercise of Rangen water rights 36-02551(priority July 13, 1962) and 36-07694 (priority April 12, 1977).
2. ~~It is our opinion that there is insufficient spring flow available to operate the Rangen facility and that the available Rangen spring flows are being utilized appropriately and efficiently according to the adjudicated water rights. There is no evidence of wasted water.~~
3. It is our opinion that the best available science (ESPAM 2.1), predicted a steady state impact of 17.9 CFS from curtailment of ground water pumping within the area of the model, under water rights junior to July 13, 1962.
4. It is our opinion that the flow measurements collected at the Rangen facility are accurate ~~and consistent with the industry practice.~~
5. It is our opinion that no alternative method of water diversion has been identified that would provide the Rangen facility additional water with a usable and acceptable quantity ~~and quality~~ that isn't already being accessed by existing Rangen intake structures.
6. It is our opinion that IDWR has appropriately developed the ESPAM 2.1 model and that the ESHMC has provided guidance and oversight of the modeling process.
7. It is our opinion that the ESPAM 2.1 model represents the best available science for simulating hydraulic behavior of the ESPA.
8. It is our opinion that the Mud Lake input data mistakes discovered in October 2012 did not have any significant impact on the ESAPM development process and that ESPAM 2.1 should be used for all IDWR ground water modeling at this time.
9. It is our opinion that the historic Rangen Spring flows presented to the ESHMC are accurate and that the ESHMC approved IDWR use of these data during calibration.
10. It is our opinion that the ESPAM 2.1 calibration quality at the Rangen Spring and other major springs and Snake River reaches indicates that the model is an excellent predictor of changes to spring flow an river reaches.
11. It is our opinion that the current IDWR ESPAM 2.1 uncertainty analysis is not sufficient or useful for quantifying the uncertainty of any particular model prediction. Its primary value will be to guide future calibrations and data collection efforts. The best available predictions of junior pumping impacts to the Rangen Spring are those made by calibrated model E121025A001 (ESPAM 2.1).
12. It is our opinion that the results of the IDWR Validation and Comparison to 1.1 exercises do not preclude the use of ESPAM 2.1 in any way.
13. It is our opinion that the IDWR curtailment methodology is reasonable and sufficient for calculating the impacts of curtailment on ESPA water levels and spring flows using the ESPAM 2.1 model..

14. It is our opinion that curtailment to mitigate injury to a senior water right is not a waste of the water resource. The relationships between ESPA water levels and Rangen Spring flows are well correlated. This correlation is an indication that ESPA well pumping and spring flows are hydraulically connected and that the spatial distribution of the correlated data indicates that the Rangen Spring source water is a large regional area.
15. It is our opinion that specific components of uncertainty (uncertainty in model inputs, calibrated aquifer parameters, observation target measurement, and numerical calculation) by themselves cannot be used as a definition of model prediction uncertainty.
16. It is our opinion that model predictive uncertainty has not been adequately quantified and that it would be inappropriate to use any adjustment to model predictions other than the calibrated ESPAM 2.1 model predictions.

G. References and Documents Relied Upon

Contor, B.A. and Johnson, G.S., 2006. Enhanced ESPA Ground Water Model, July, 2006, Idaho Water Resources Research Institute, University of Idaho.

Covington, H.R. and Weaver, J.N., 1990. Geologic map and profile of the north wall of the Snake River Canyon. U.S. Geological Survey Miscellaneous Investigation Series, Maps I-1947A through I-1947E.

Covington, H.R. and Weaver, J.N., 1991. Geologic Maps and Profiles of the North Wall of the Snake River Canyon Thousand Springs and Niagara Springs Quadrangle, Idaho. USGS Misc. Investigations Series, Map 1-1947-C. U.S. Geological Survey, Boise, ID.

Cosgrove, D.M., Contour, B.A., and Johnson, G.S., 2006. Enhanced Eastern Snake Plain Aquifer Model Final Report. Idaho Water Resources Technical Report 06-002. July, 2006.

Dakins, M., 2012. The Statistical Evaluation of the ESPAM2 Model. White Paper Presented to the ESHMC June 22, 2012.

Doherty, J., 2004. PEST Model-Independent Parameter Estimation Users Manual, Watermark Numerical Computing, 336 Cliveden Avenue, Corinda 4075, Brisbane, Australia.

Dreyer, K., 2004. February 25, 2004 IDWR Order requiring curtailment of junior priority rights in Water District No. 130 effective April 1, 2003.

Erwin, F., 2012. Deposition of Frank Ervin, Sept. 13, 2012.

Farmer, N., 2009. Review of Hydrogeologic Conditions Located at and Adjacent to the Spring at Rangen Inc., Idaho Department of Water Resources Open File Report. March 4, 2009.

Hamilton, J.R., 2004. "Economic Importance of ESPA-Dependent Spring flow to the Economy of Idaho, Hamilton Water Economics, 2004.

Hill, M.C., and Tiedeman, C.R., 2007. Effective Calibration of Environmental Models with Analysis of Data, Sensitivities, Prediction and Uncertainty.

HRS Water Consultants, Inc, 2007. Evaluation of Localized Spring Flow Source Areas from Crystal Spring to Box Canyon Spring. September, 2007.

IDWR, 2012. Draft Enhanced Snake Plain Aquifer Model Version 2.1 Final Report, Idaho Department of Water Resources with guidance from the Eastern Snake Plain Hydrologic Modeling Committee.

Janczak, L., 2001. Relationships between Spring Discharge and Aquifer Water Levels in the Thousand Spring Region, Idaho. M.S. Thesis, University of Idaho, October 2001.

Johnson, G.S. et al., 2002. Spring discharge along the Milner to King Hill Reach of the Snake River, Idaho Water Resources Research Institute.

Koreny, J., 2008. "Research on ESPA Ground Water Conditions and Eastern Snake Plain Aquifer Model in Preparation for the Blue Lakes Trout Farm Delivery Call". Memo to Dan Steenson, November 2008.

Koreny, J., Brockway, C.E., Schreuder, W., Bowling, J., Brannon, J., 2009. White Paper Technical Evaluation of Trim Line. Submitted to the Eastern Snake Hydrologic Modeling Committee.

May, Sudweeks, and Browning, 2004. Letter to Idaho Department of Commerce and Labor, "Rangen, Inc. Applications for Aquifer Mitigation Assistance Grants".

Ralston Hydrologic Services, Inc., 2008. Hydrogeology of the Thousand Springs to Malad Reach of the Enhanced Snake Plain Aquifer Model, September 2008.

Rangen, 2012. http://rangen.com/history.html , accessed 9/4/12.

Raymondi, R., 2012. Rick Raymondi email to ESHMC dated November 27, 2012.

Sukow, J., 2012b. DRAFT Comparison of Eastern Snake Plain Aquifer Model Version 2.1 with Version 1.1 via the Curtailment Scenario, Idaho Department of Water Resources. November 26, 2012.

Sukow, J., 2012a. Comparison of Superposition Model with Fully Populated Model for Eastern Snake Plain Aquifer Model Version 2.0, Idaho Department of Water Resources. July 18, 2012.

Shaw, D., 2008. "Review of Allocation of Replacement Water in the Thousand Springs Area." Memo to John Simpson, November 2008.

U.S. Bureau of Reclamation, 2001. Water Measurement Manual, U.S. Bureau of Reclamation, Denver, CO.

U.S. Department of the Interior, 1984. Techniques of Water-Resources Investigations of the USGS, Discharge Measurements at Gauging Stations: Book 3, Chapter A8 pg 3, 1984.

U.S. Dept. of the Interior, 1984. Techniques of Water-Resources Investigations of the USGS, Computation of Continuous Records of Streamflow : Book 3 Chapter A13 pgs 45-52, 1984.

USGS, 1958. Records of springs in the Snake River valley, Jerome and Gooding Counties, Idaho, 1899-1947,1958, Nace, Raymond L.; Van't Hul, A., McQueen, I. S., USGS Water Supply Paper: 1463.

Whitehead, R.L., 1986, Geohydrologic framework of the Snake River Plain, Idaho and Eastern Oregon. Atlas HA-681.

Wylie, A., 2012a. DRAFT Enhanced Snake Plain Aquifer Model Version 2.1 Uncertainty Analysis, Idaho Department of Water Resources, December 2012.

Wylie, A., 2012b. DRAFT ESPAM2.1 2009-2010 Validation Scenario and 1900 Validation Scenario Report, Idaho Department of Water Resources, December 2012.

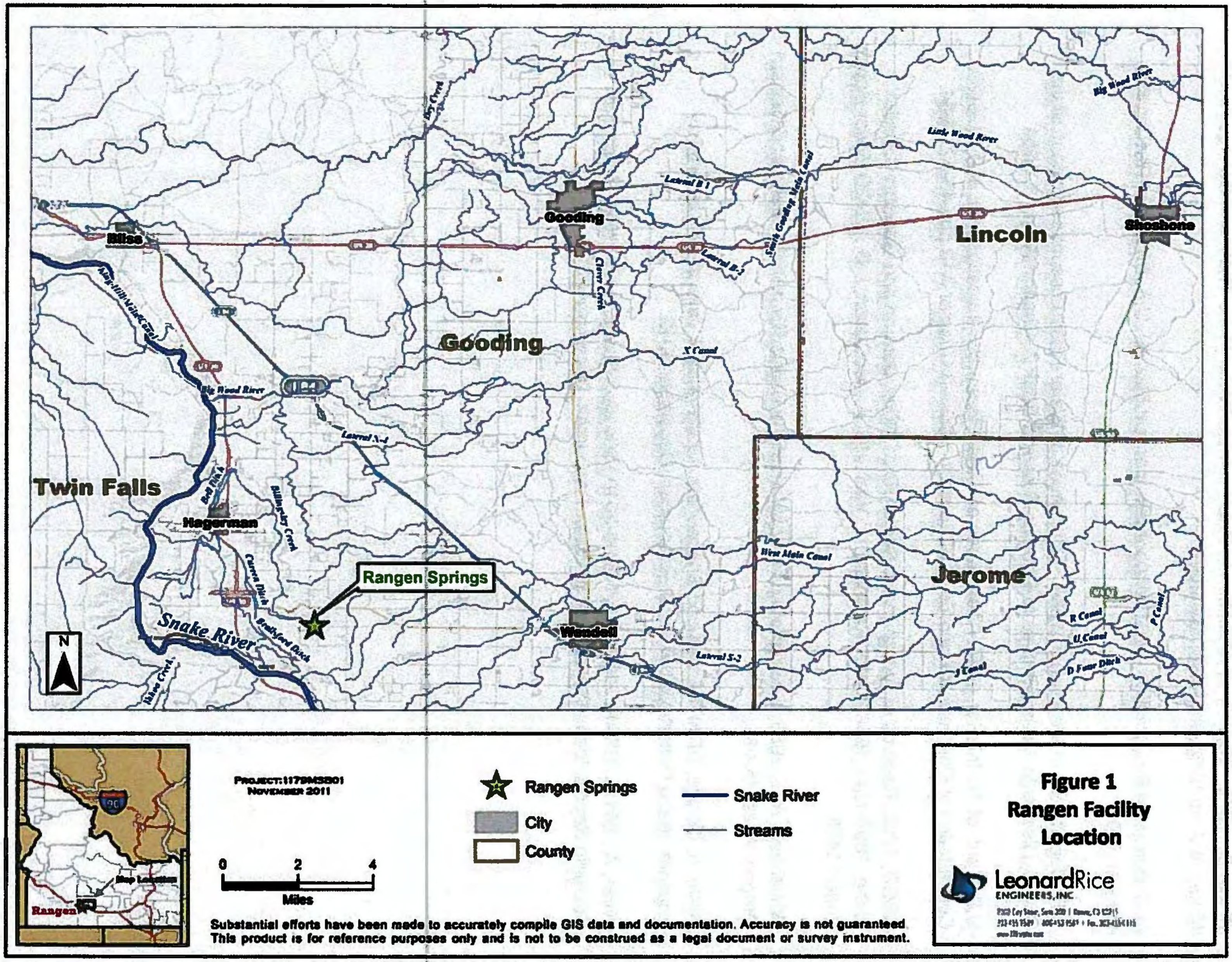


Figure 1
Rangen Facility Location

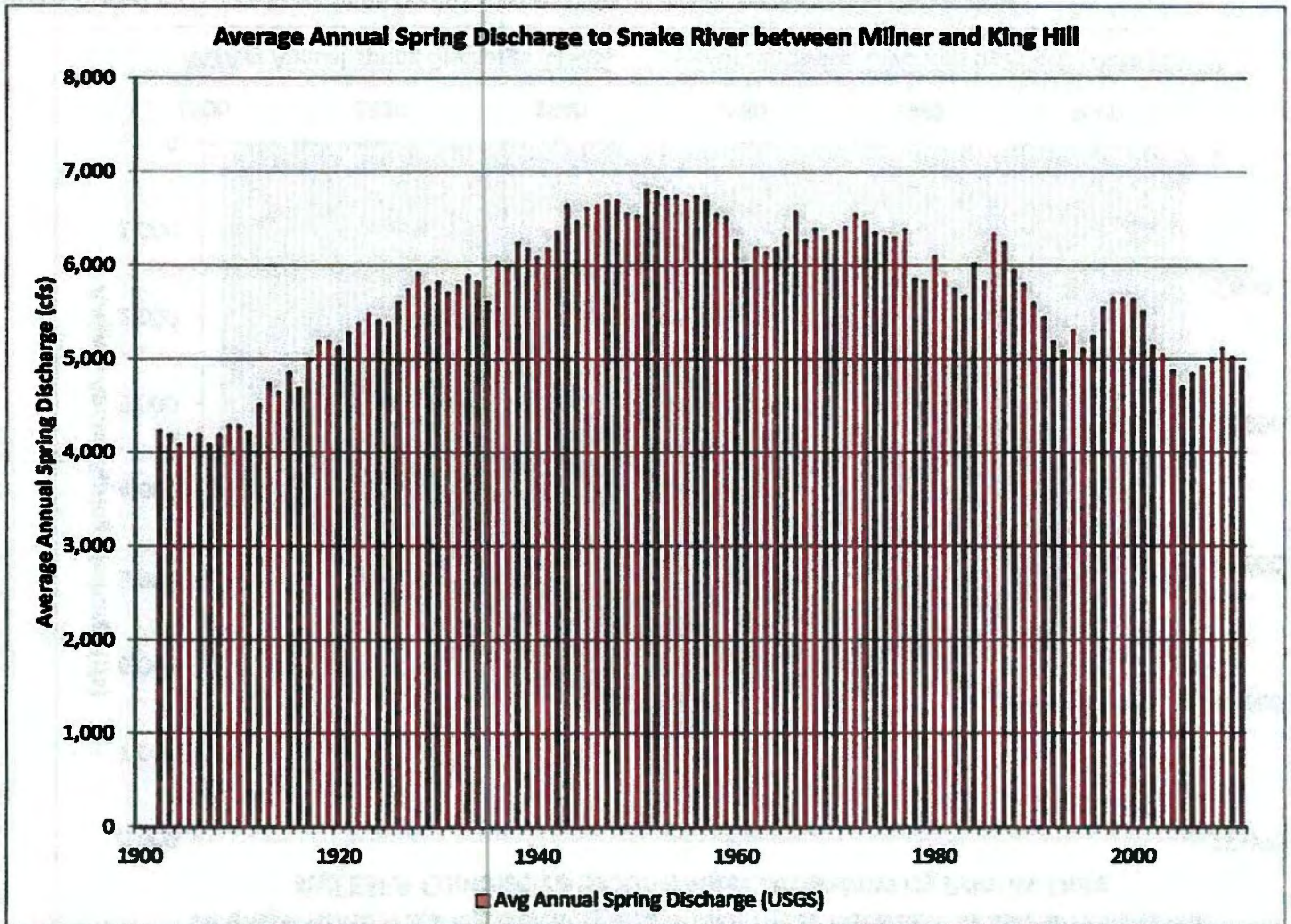


Figure 2. Total ESPA Spring Flow

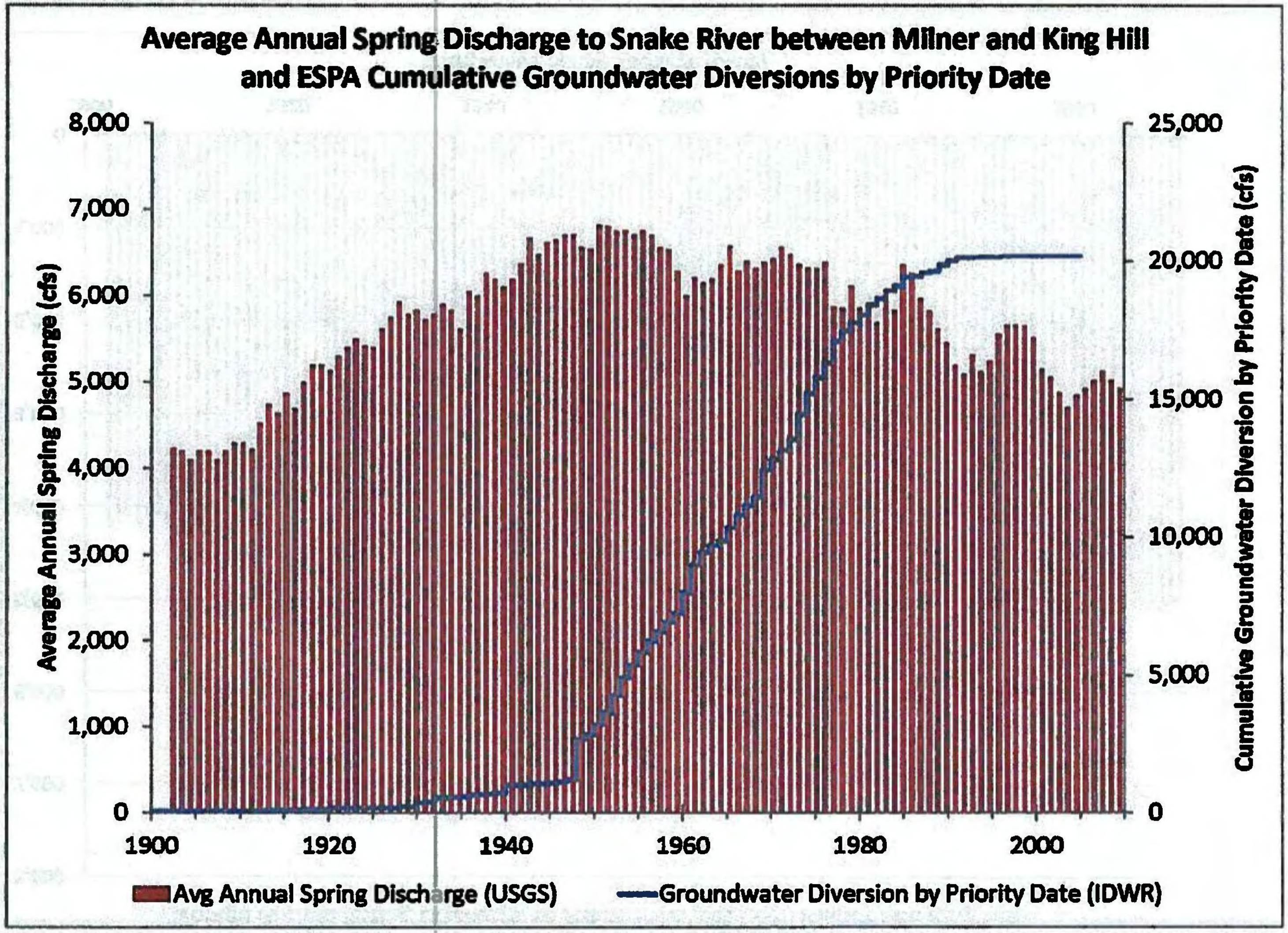


Figure 3. Eastern Snake River Plain Ground Water Rights vs. Estimated Northside Spring Flow

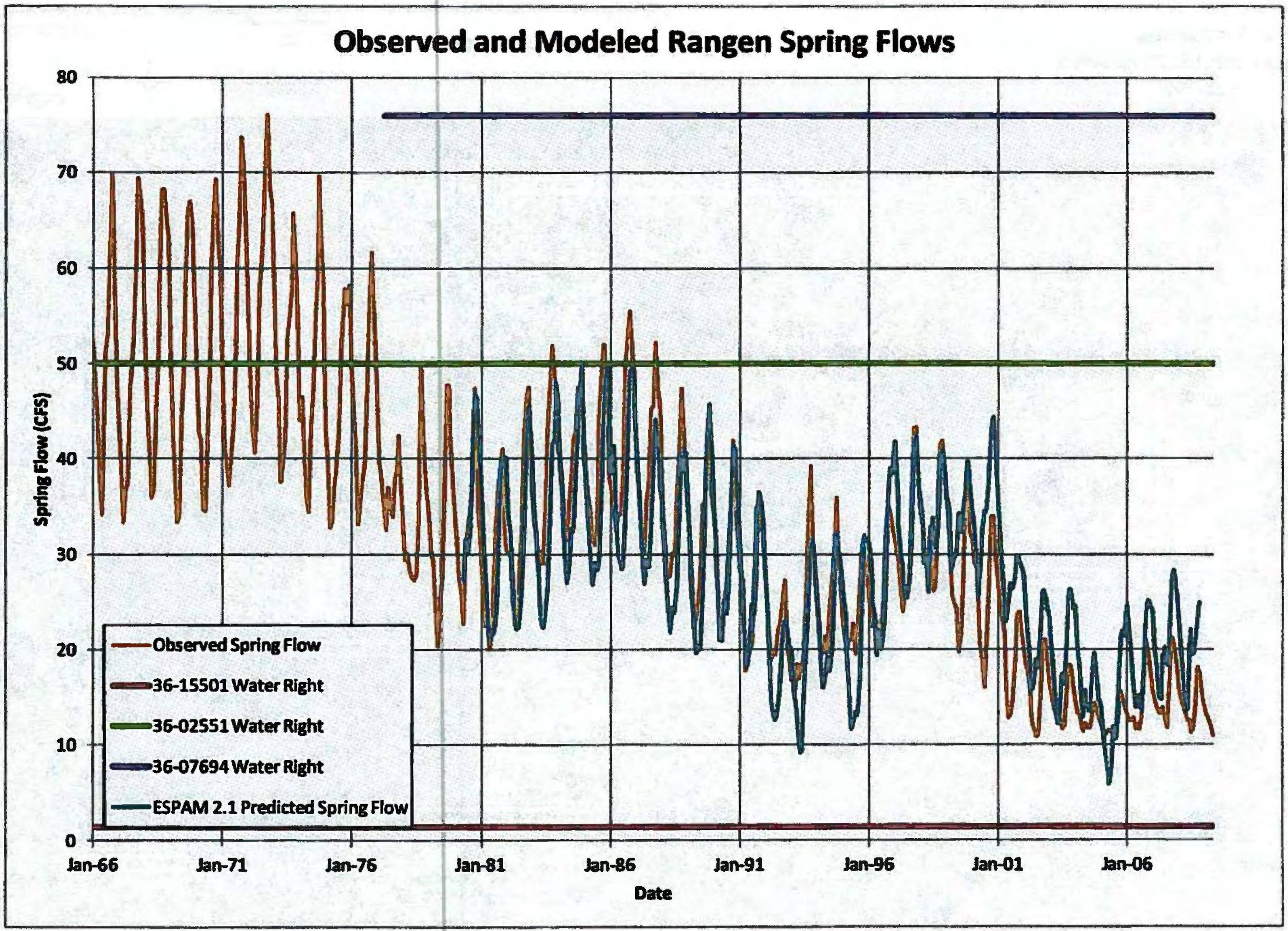


Figure 4. Rangen Spring Flows – Observed and Modeled

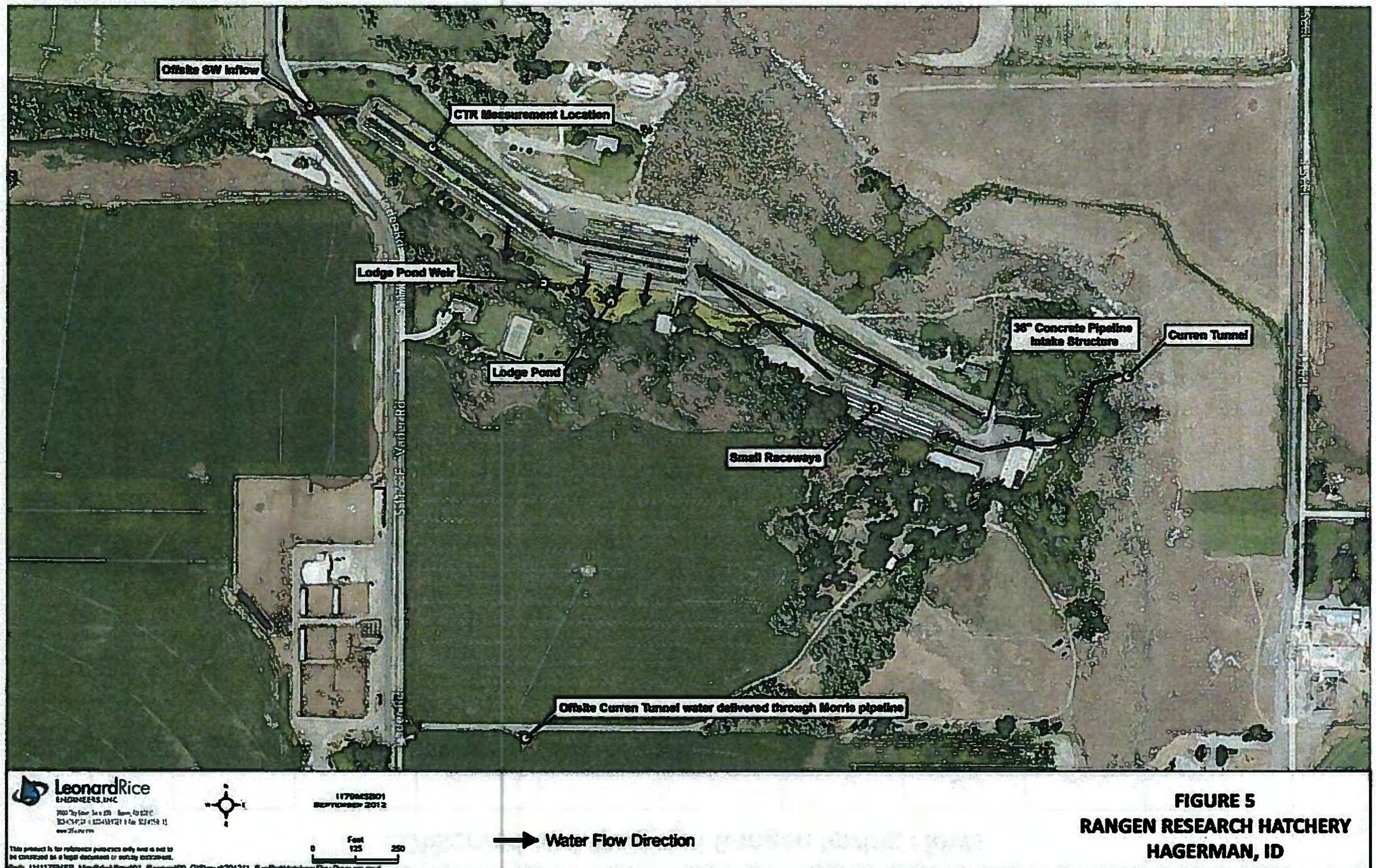


FIGURE 5
RANGEN RESEARCH HATCHERY
HAGERMAN, ID

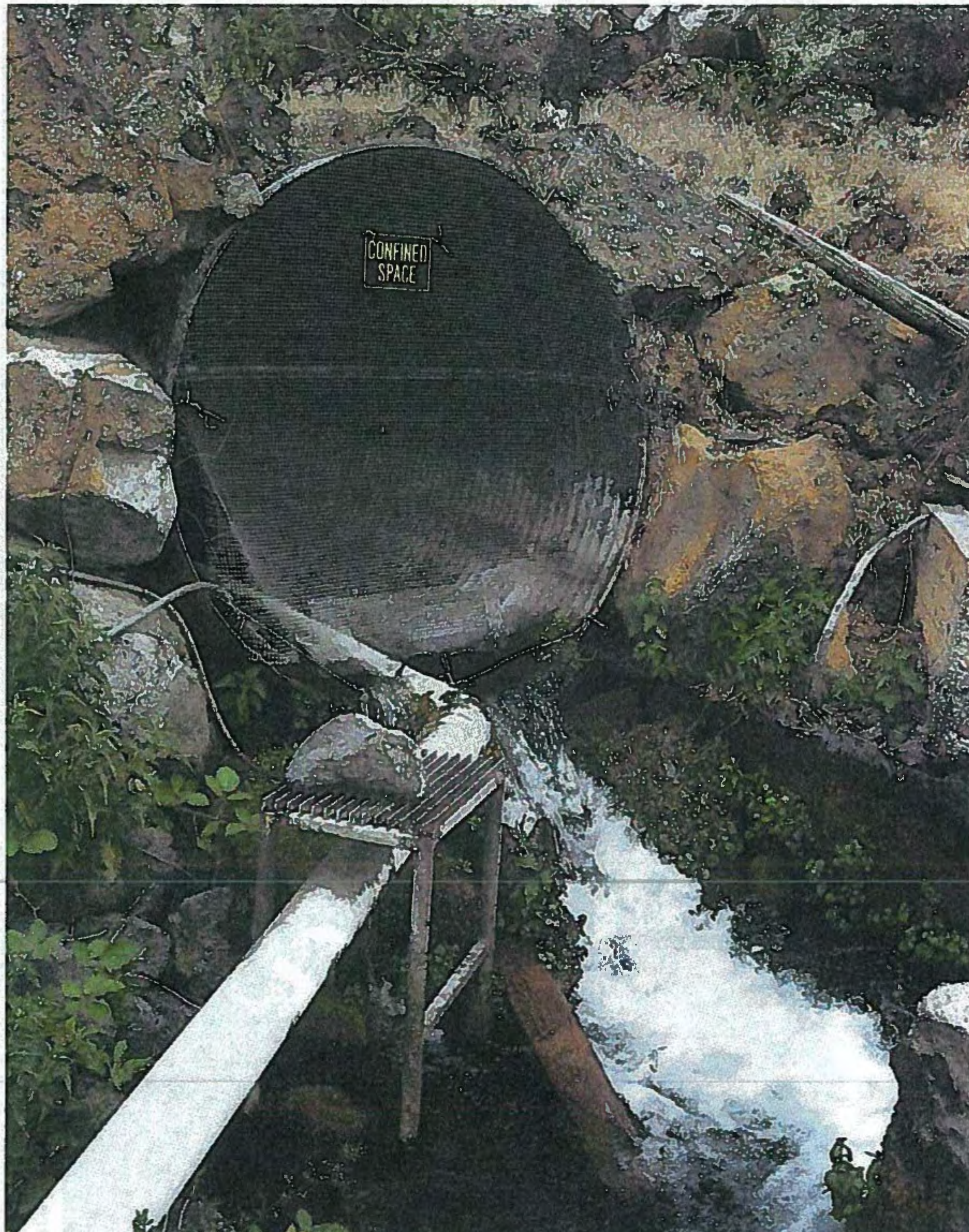


Figure 6. Photo Showing Curren Tunnel

Figure 7. Photo Showing Curren Tunnel and Pipelines

Figure 8. Photo Showing Rangen Large Raceways Intake Structure

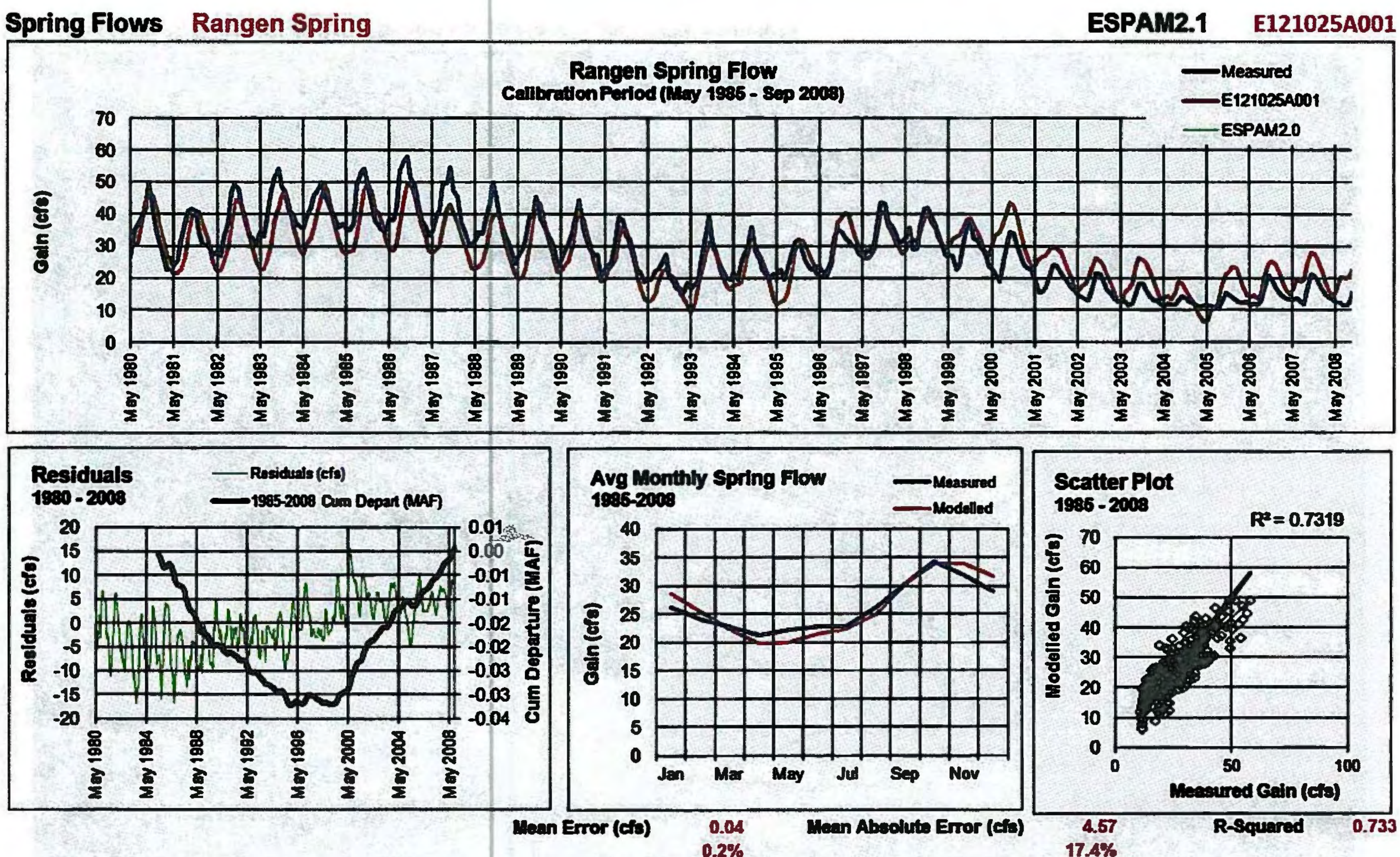


Figure 9. IDWR ESPAM 2.1 Rangen Spring Calibration Results (Adapted from IDWR, 2012)

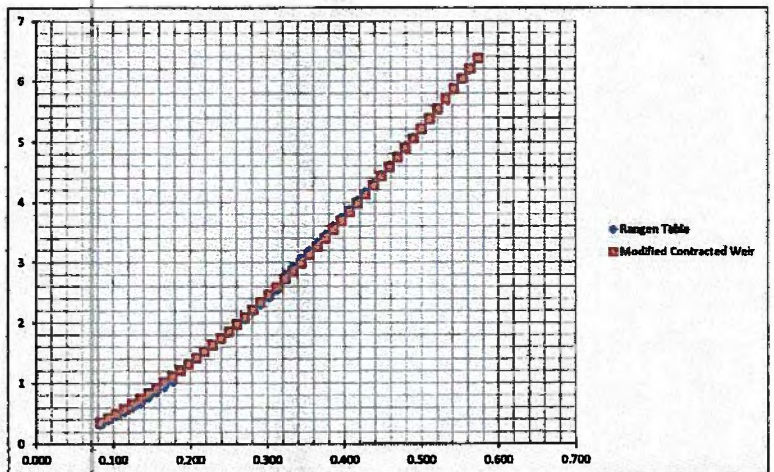
Appendix A
Comparison of Rangen Weir Flow Calculations

RANGEN Appendix A Comparison of Rangen Weir Flow Calculations
Rangen CTR Raceway Discharge Rating
Head is measured over check boards at end of first bay of CTR Raceways
Only one Raceway was operating on 9/18/2012

As a suppressed weir

Width	58.5 inches	4.875 ft	Rangen CTR keyways
Equation	Qs=3.33 *L*h^1.5	(Francis Formula)	Std. Suppressed weir
	Qc=3.33 *(L-.2H)*h^1.5		Std Contracted Weir
	Qr		Rangen Rating Table

H (inches)	H(feet)	Qs cfs	Qc	Qr	3.09 Qtc	Qts	4 Absolut % Diff Qc-Qr
1	0.083	0.39	0.39	0.33	0.36	0.47	0.15
1 1/8	0.094	0.47	0.46	0.4	0.43	0.56	0.14
1 1/4	0.104	0.55	0.54	0.47	0.50	0.66	0.14
1 3/8	0.115	0.63	0.63	0.54	0.58	0.76	0.14
1 1/2	0.125	0.72	0.71	0.61	0.66	0.86	0.15
1 5/8	0.135	0.81	0.80	0.69	0.75	0.97	0.14
1 3/4	0.146	0.90	0.90	0.77	0.83	1.09	0.14
1 7/8	0.156	1.00	1.00	0.86	0.92	1.20	0.14
2	0.167	1.10	1.10	0.95	1.02	1.33	0.13
2 1/8	0.177	1.21	1.20	1.04	1.11	1.45	0.13
2 1/4	0.188	1.32	1.31	1.22	1.21	1.58	0.07
2 3/8	0.198	1.43	1.42	1.32	1.32	1.72	0.07
2 1/2	0.208	1.54	1.53	1.42	1.42	1.85	0.07
2 5/8	0.219	1.66	1.65	1.53	1.53	2.00	0.07
2 3/4	0.229	1.78	1.76	1.63	1.64	2.14	0.08
2 7/8	0.240	1.90	1.89	1.74	1.75	2.29	0.08
3	0.250	2.03	2.01	1.85	1.86	2.44	0.08
3 1/8	0.260	2.16	2.13	1.96	1.98	2.59	0.08
3 1/4	0.271	2.29	2.26	2.07	2.10	2.75	0.09
3 3/8	0.281	2.42	2.39	2.19	2.22	2.91	0.08
3 1/2	0.292	2.56	2.53	2.31	2.34	3.07	0.09
3 5/8	0.302	2.70	2.66	2.43	2.47	3.24	0.09
3 3/4	0.313	2.84	2.80	2.55	2.60	3.41	0.09
3 7/8	0.323	2.98	2.94	2.8	2.73	3.58	0.05
4	0.333	3.12	3.08	2.93	2.86	3.75	0.05
4 1/8	0.344	3.27	3.23	3.06	2.99	3.93	0.05
4 1/4	0.354	3.42	3.37	3.19	3.13	4.11	0.05
4 3/8	0.365	3.57	3.52	3.33	3.27	4.29	0.05
4 1/2	0.375	3.73	3.67	3.46	3.41	4.48	0.06
4 5/8	0.385	3.88	3.82	3.6	3.55	4.67	0.06
4 3/4	0.396	4.04	3.98	3.74	3.69	4.86	0.06
4 7/8	0.406	4.20	4.13	3.88	3.84	5.05	0.06
5	0.417	4.37	4.29	4.03	3.98	5.24	0.06
5 1/8	0.427	4.53	4.45	4.17	4.13	5.44	0.06
5 1/4	0.438	4.70	4.61	4.31	4.28	5.64	0.07
5 3/8	0.448	4.87	4.78	4.46	4.43	5.85	0.07
5 1/2	0.458	5.04	4.94	4.61	4.59	6.05	0.07
5 5/8	0.469	5.21	5.11	4.76	4.74	6.26	0.07
5 3/4	0.479	5.38	5.28	4.92	4.90	6.47	0.07
5 7/8	0.490	5.56	5.45	5.07	5.06	6.68	0.07
6	0.500	5.74	5.62	5.23	5.22	6.89	0.07
6 1/8	0.510	5.92	5.80	5.38	5.38	7.11	0.07
6 1/4	0.521	6.10	5.97	5.54	5.54	7.33	0.07
6 3/8	0.531	6.29	6.15	5.7	5.71	7.55	0.07
6 1/2	0.542	6.47	6.33	5.86	5.87	7.77	0.07
6 5/8	0.552	6.66	6.51	6.03	6.04	8.00	0.07
6 3/4	0.563	6.85	6.69	6.19	6.21	8.23	0.07
6 7/8	0.573	7.04	6.87	6.36	6.38	8.46	0.07
					AVG		0.08



Remark: Discharge table used by Rangen employees appears to match most closely with a standard contracted weir formula with a coefficient of 3.09 rather than the standard 3.33 coefficient.
This would account for the fact that the 2 inch boards over which water flows are not sharp crested as is assumed in the standard rectangular contracted weir formula.
There are two minor step functions in the Rangen discharge table for which there is no apparent reason, at approximately H=.18 ft(2 1/8 in.) and 0.32 ft (3 7/8 in).

The use of a modified weir coefficient of 3.09 applied to board overflow is consistent with standard practice on aquaculture facilities

INCHES		LG RW	CTR	SM	DAM
	0	0.25	0.33	0.23	0.28
	1/8	0.30	0.40	0.27	0.33
	1/4	0.35	0.47	0.31	0.39
	3/8	0.41	0.54	0.36	0.45
	1/2	0.47	0.61	0.41	0.51
1	5/8	0.52	0.69	0.47	0.57
1	3/4	0.59	0.77	0.52	0.64
	7/8	0.65	0.86	0.58	0.71
2	0	0.72	0.95	0.64	0.78
2	1/8	0.79	1.04	0.70	0.86
2	1/4	0.93	1.22	0.82	1.01
2	3/8	1.00	1.32	0.89	1.09
2	1/2	1.08	1.42	0.96	1.18
2	5/8	1.16	1.53	1.03	1.26
2	3/4	1.24	1.63	1.10	1.35
2	7/8	1.32	1.74	1.17	1.44
3	0	1.40	1.85	1.24	1.53
3	1/8	1.48	1.96	1.32	1.62
3	1/4	1.57	2.07	1.40	1.72
3	3/8	1.66	2.19	1.47	1.81
3	1/2	1.75	2.31	1.55	1.91
3	5/8	1.84	2.43	1.63	2.01
3	3/4	1.93	2.55	1.72	2.11
3	7/8	2.12	2.80	1.89	2.32
4	0	2.22	2.93	1.97	2.43
4	1/8	2.32	3.06	2.06	2.53
4	1/4	2.42	3.19	2.15	2.64
4	3/8	2.52	3.33	2.24	2.75
4	1/2	2.62	3.46	2.33	2.87
4	5/8	2.73	3.60	2.42	2.98
4	3/4	2.83	3.74	2.52	3.10
4	7/8	2.94	3.88	2.61	3.21
5	0	3.05	4.02	2.71	3.33
5	1/8	3.16	4.17	2.80	3.45
5	1/4	3.27	4.31	2.90	3.57
5	3/8	3.38	4.46	3.00	3.69
5	1/2	3.49	4.61	3.10	3.82
5	5/8	3.61	4.76	3.20	3.94
5	3/4	3.72	4.92	3.31	4.07
5	7/8	3.84	5.07	3.41	4.20
6	0	3.96	5.23	3.52	4.33
6	1/8	4.08	5.38	3.62	4.46
6	1/4	4.20	5.54	3.73	4.59
6	3/8	4.32	5.70	3.84	4.72
6	1/2	4.44	5.86	3.95	4.86
6	5/8	4.57	6.03	4.06	4.99
6	3/4	4.69	6.19	4.17	5.13
6	7/8	4.82	6.36	4.28	5.27

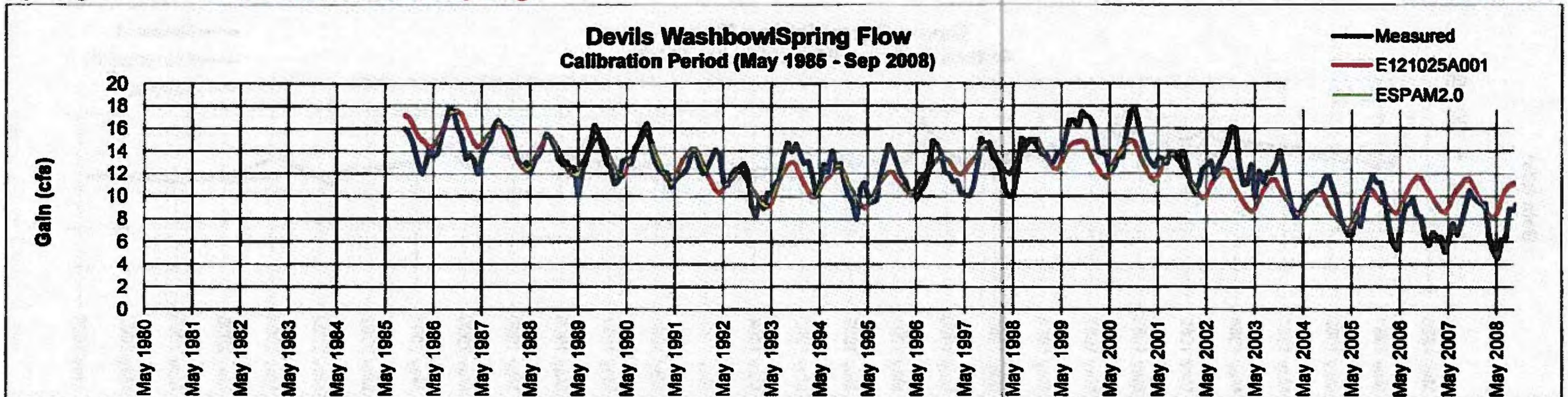
** table adjusted for measurement over 2" boards

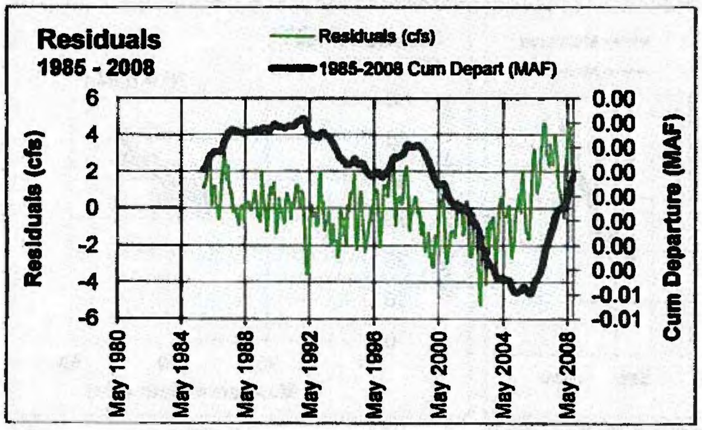
Appendix B

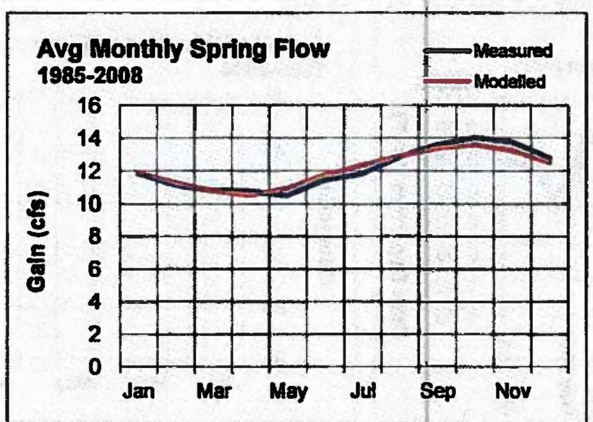
IDWR ESPAM 2.1 Spring Statistics

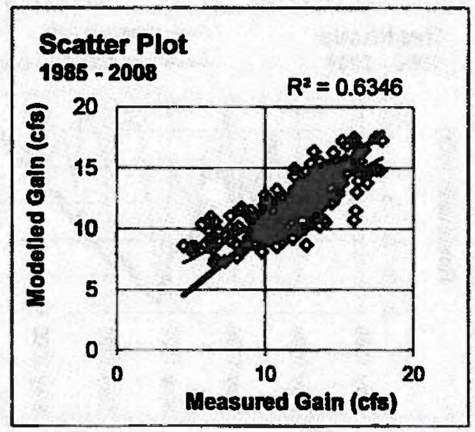
ESPAM Calibration Charts
Spring Flows

Spring Flows **Devils Washbowl Spring** **ESPAM2.1** **E121025A001**





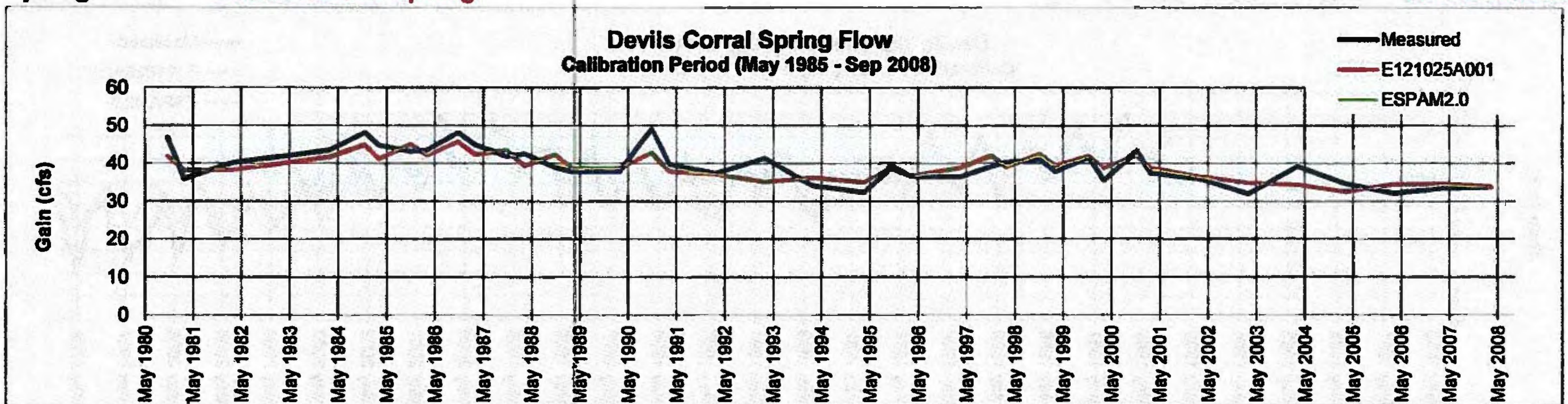


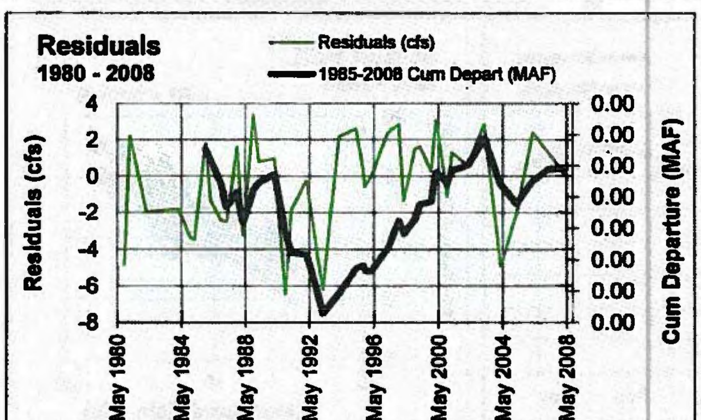


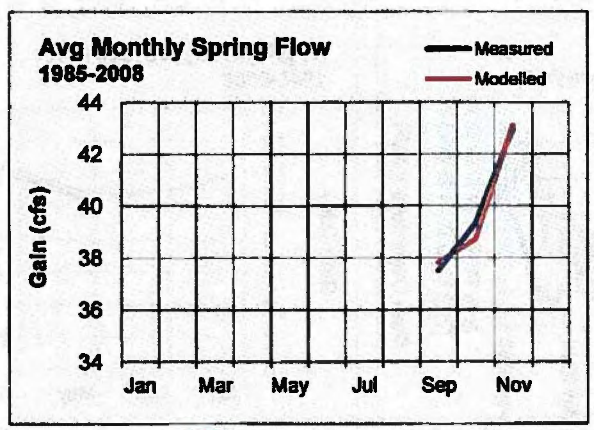
Mean Error (cfs)	-0.01 -0.1%	Mean Absolute Error (cfs)	1.26 10.4%	R-Squared	0.635

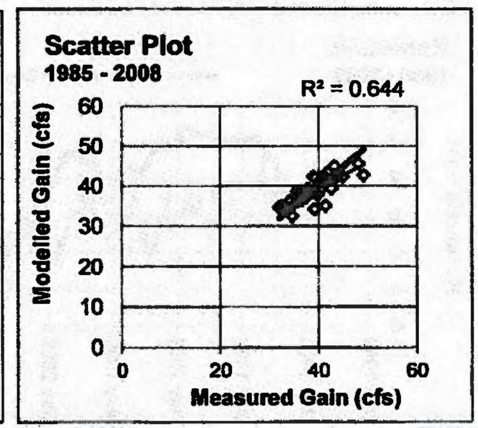
ESPAM Calibration Charts
Spring Flows

Spring Flows Devils Corral Spring **ESPAM2.1** E121025A001





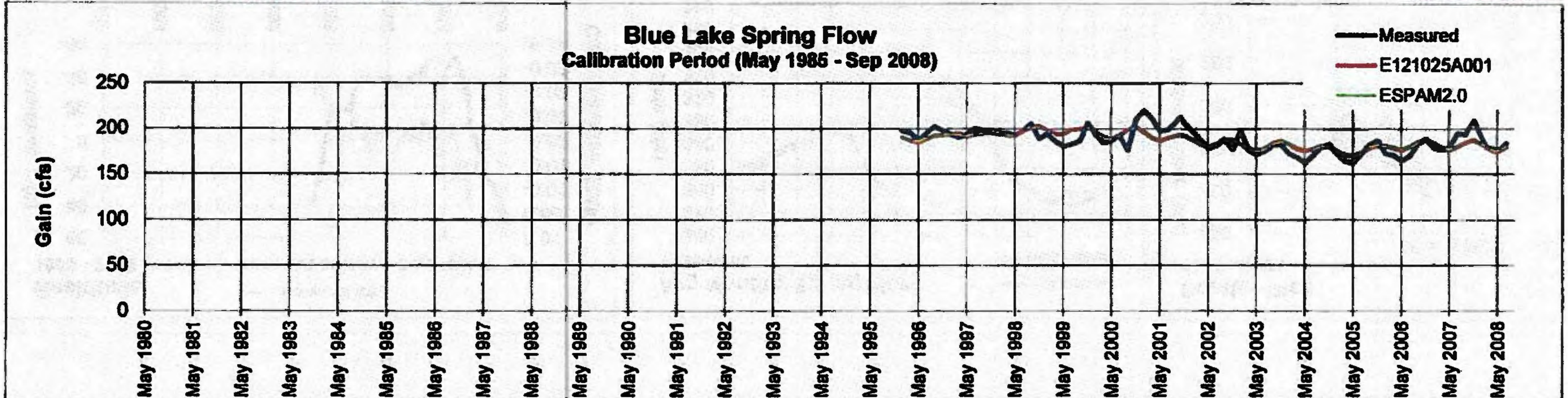


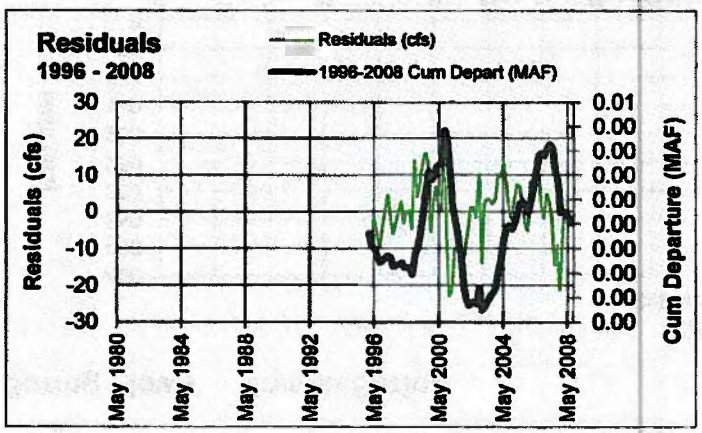


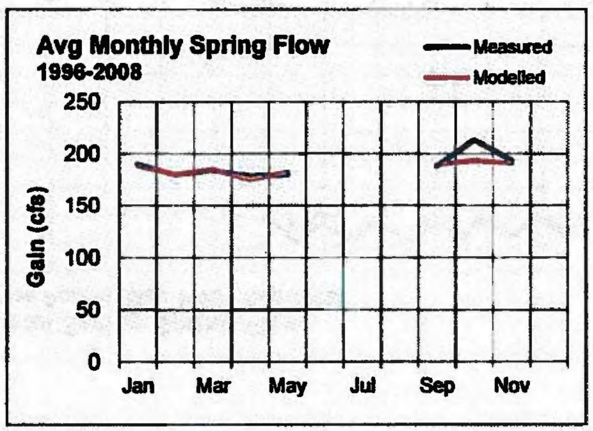
Mean Error (cfs) -0.01 0.0% **Mean Absolute Error (cfs)** 2.00 5.1% **R-Squared** 0.644

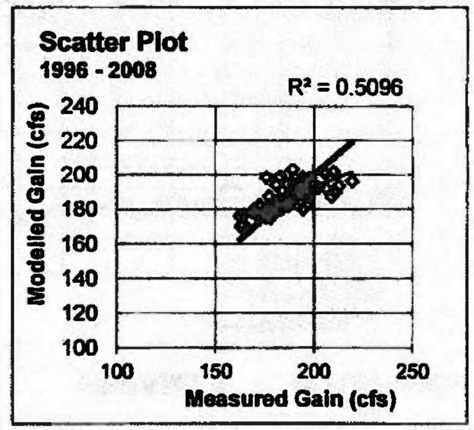
ESPAM Calibration Charts
Spring Flows

Spring Flows **Blue Lake Spring** **ESPAM2.1** **E121025A001**





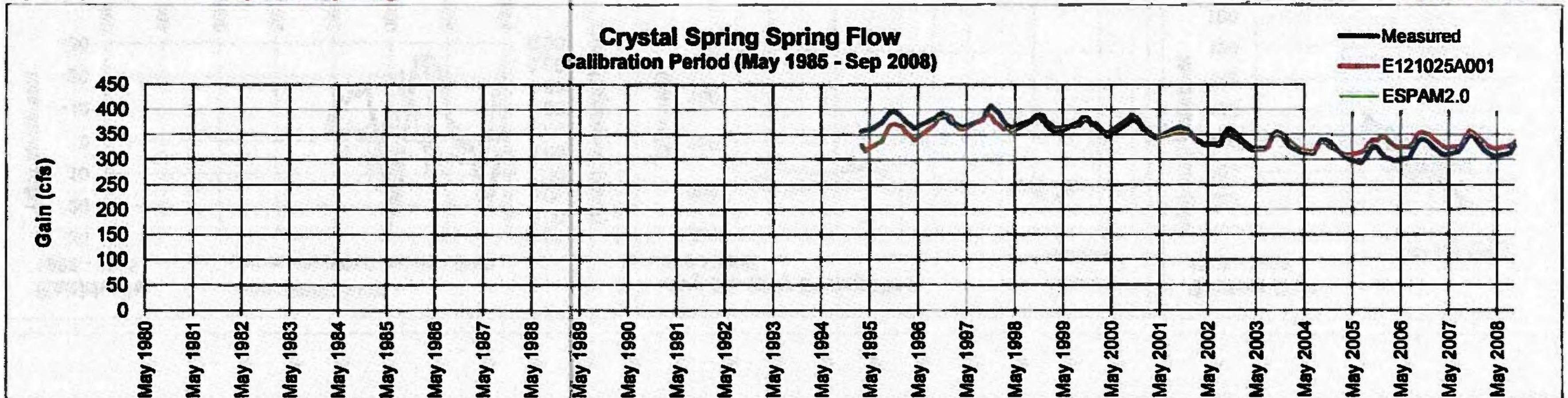


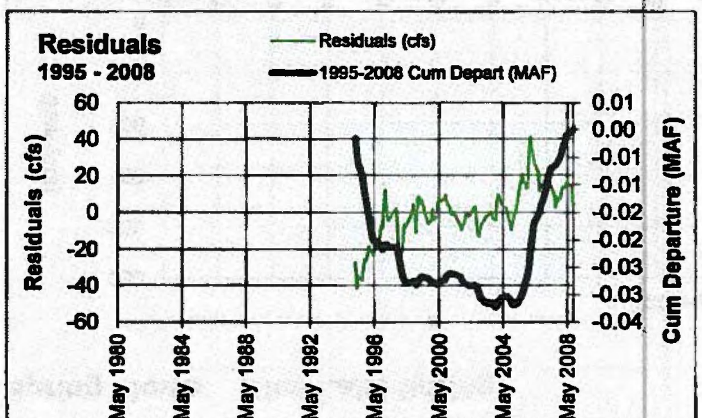


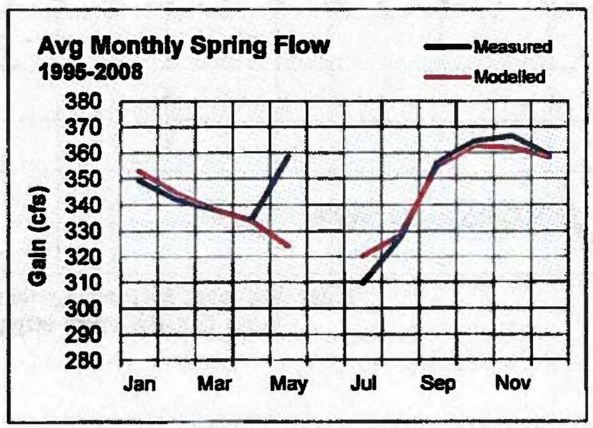
Mean Error (cfs)	0.01	Mean Absolute Error (cfs)	6.97	R-Squared	0.510
	0.0%		0.0%		

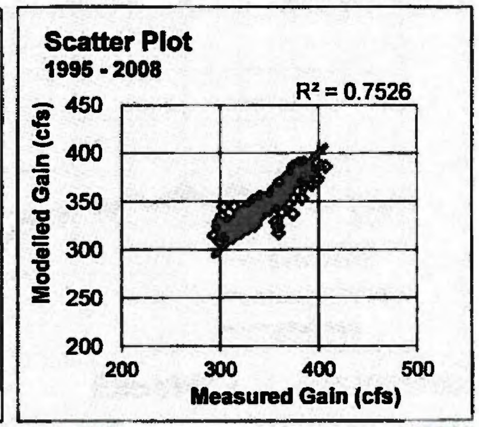
ESPAM Calibration Charts
Spring Flows

Spring Flows Crystal Spring **ESPAM2.1** E121025A001





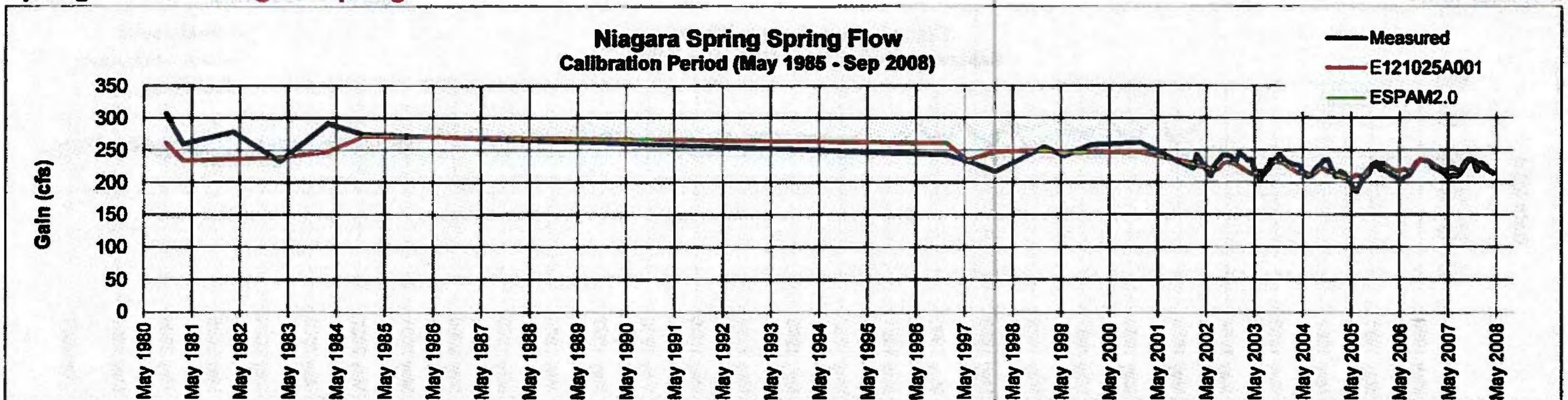


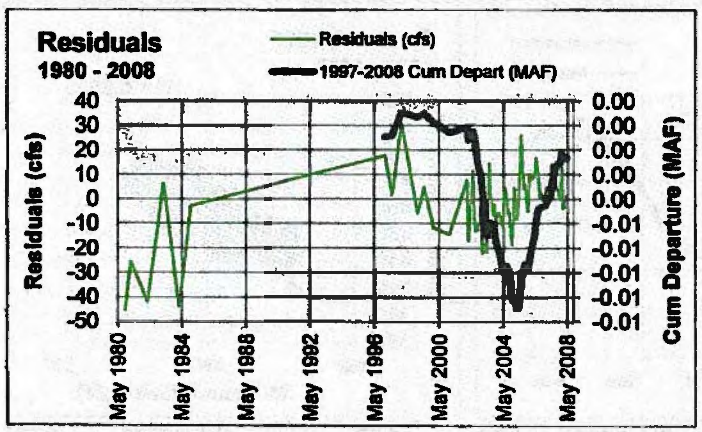


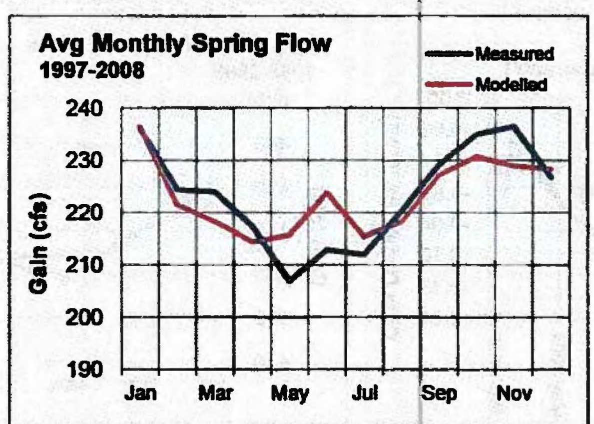
Mean Error (cfs)	0.03 0.0%	**Mean Absolute Error (cfs)**	10.67 3.1%	**R-Squared**	0.753

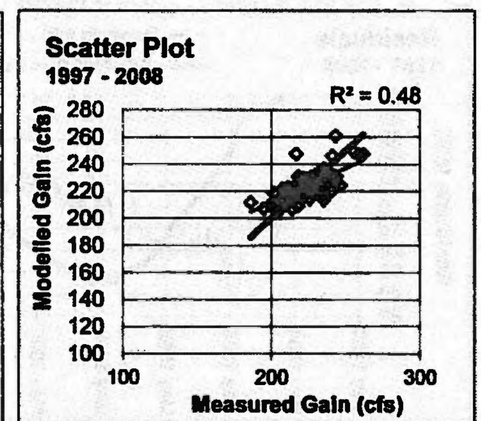
ESPAM Calibration Charts
Spring Flows

Spring Flows **Niagara Spring** **ESPAM2.1** **E121025A001**





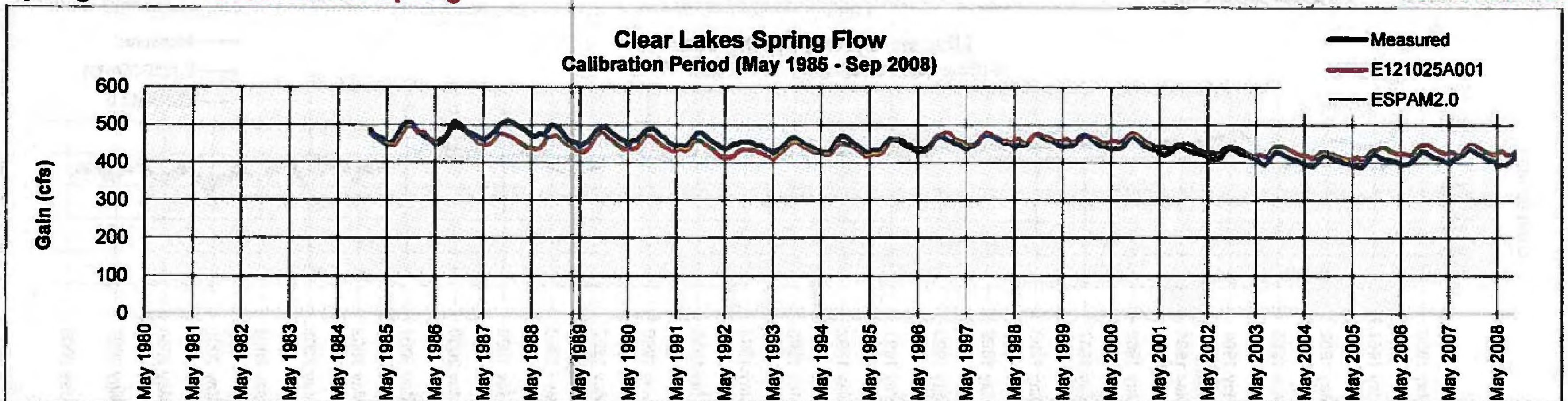


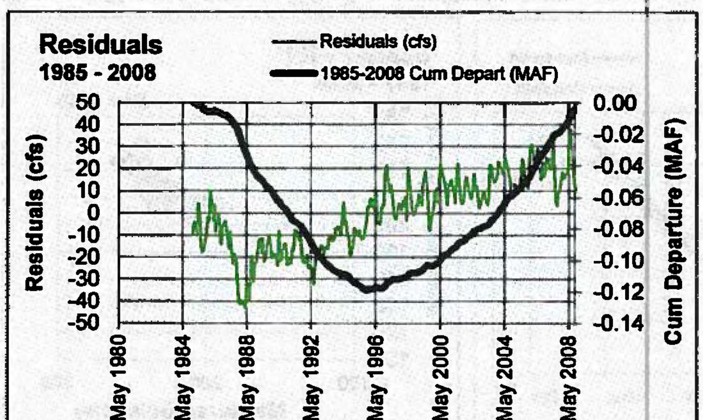


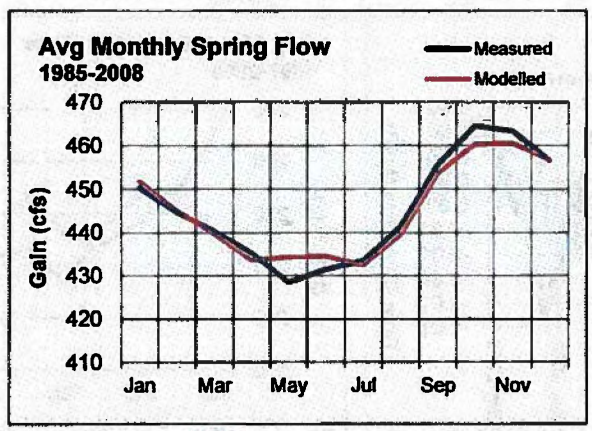
Mean Error (cfs) -0.12 -0.1% **Mean Absolute Error (cfs)** 8.12 3.6% **R-Squared** 0.480

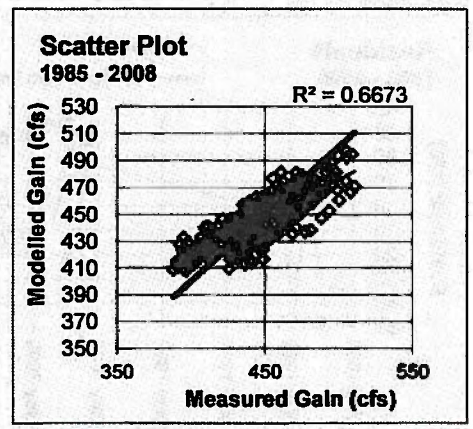
ESPAM Calibration Charts
Spring Flows

Spring Flows Clear Lakes Spring **ESPAM2.1** E121025A001





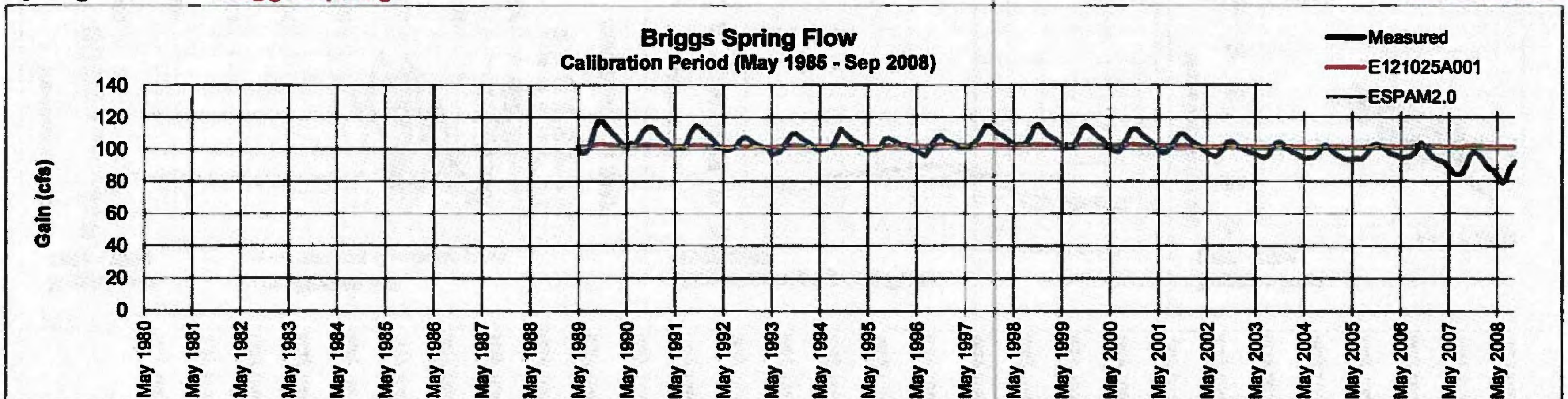


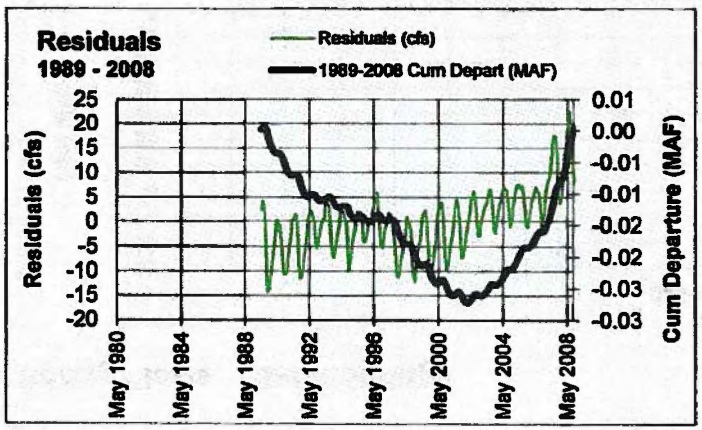


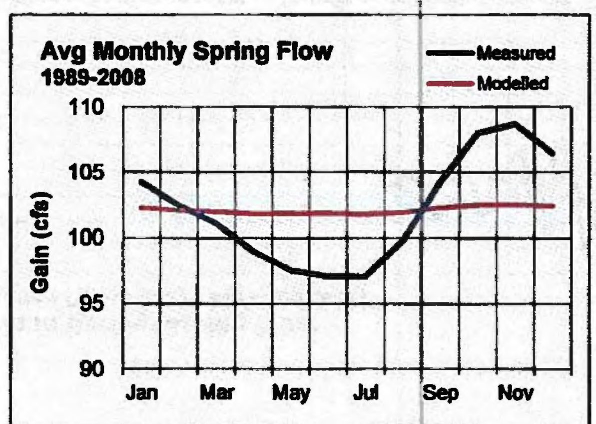
Mean Error (cfs) -0.23 -0.1% **Mean Absolute Error (cfs)** 13.97 3.1% **R-Squared** 0.667

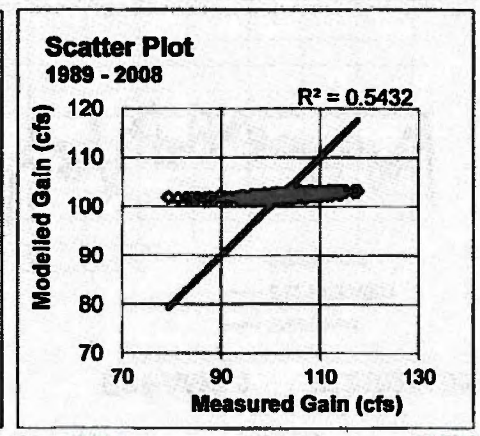
ESPAM Calibration Charts
Spring Flows

Spring Flows Briggs Spring **ESPAM2.1** E121025A001





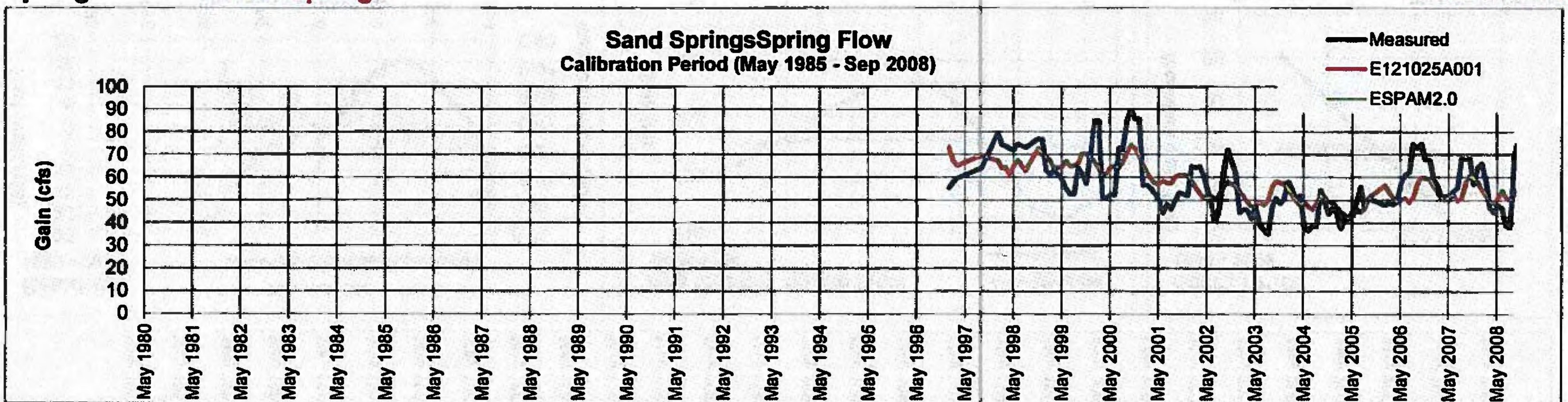


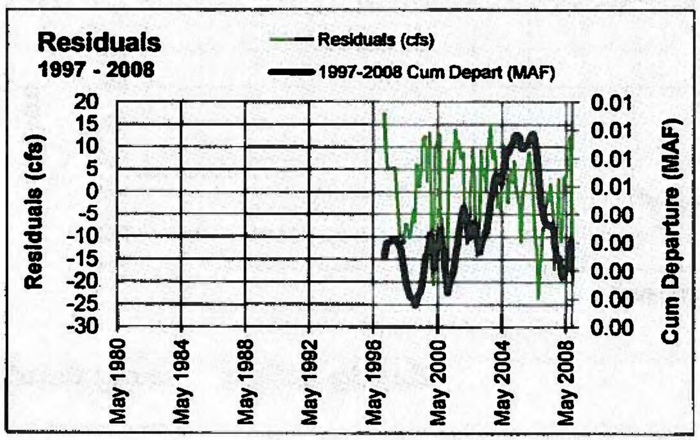


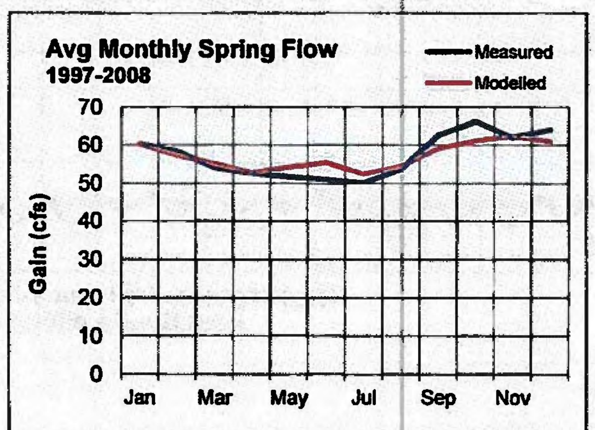
Mean Error (cfs) 0.03 0.0% **Mean Absolute Error (cfs)** 4.79 4.7% **R-Squared** 0.543

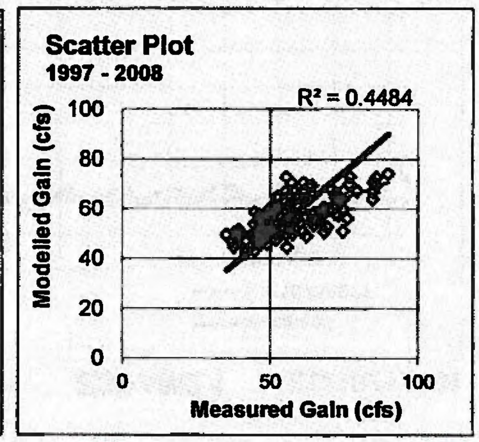
ESPAM Calibration Charts
Spring Flows

Spring Flows **Sand Springs** **ESPAM2.1** **E121025A001**





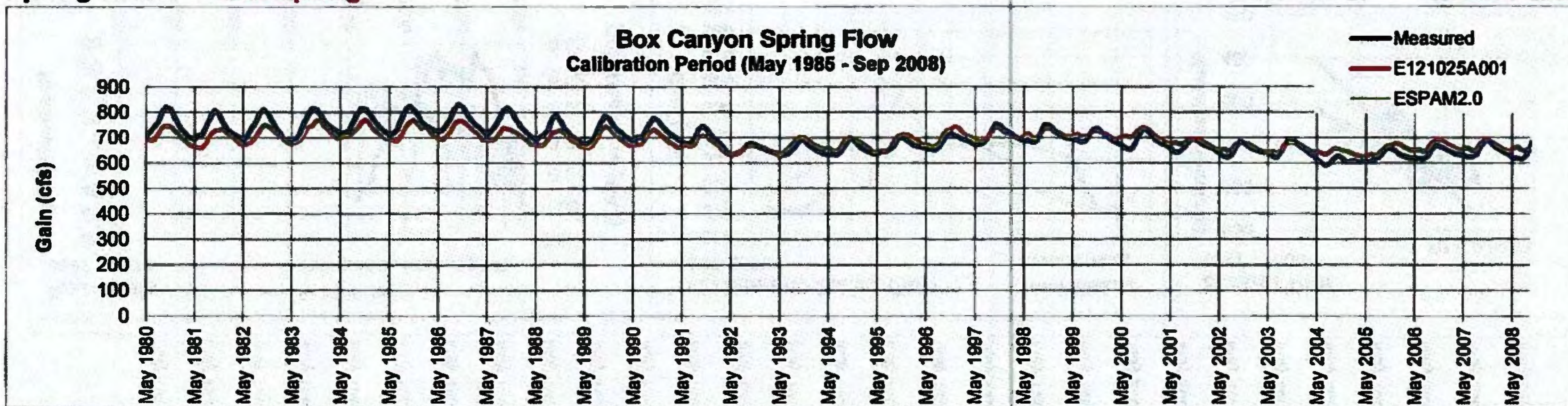


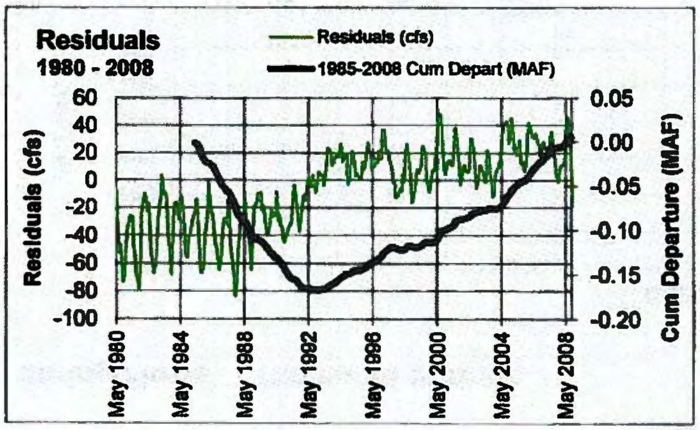


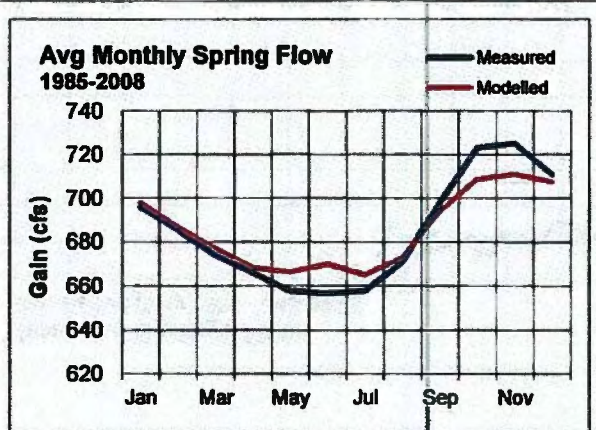
Mean Error (cfs)	-0.01	Mean Absolute Error (cfs)	7.89	R-Squared	0.448
	0.0%		13.8%		

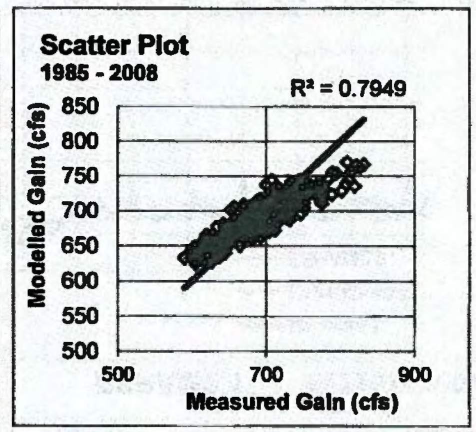
ESPAM Calibration Charts
Spring Flows

Spring Flows **Box Spring** **ESPAM2.1** **E121025A001**





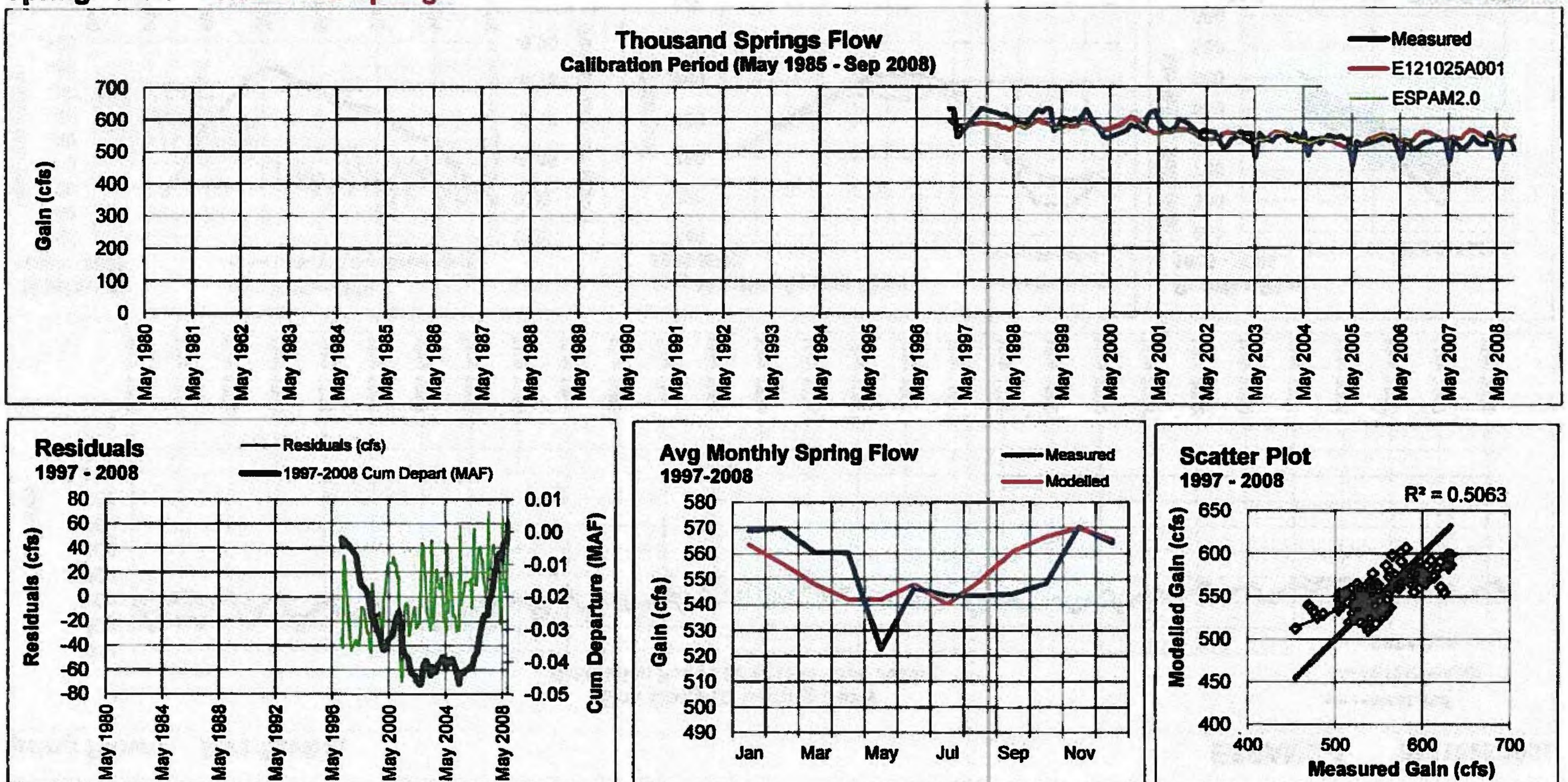




Mean Error (cfs)	0.37 0.1%	**Mean Absolute Error (cfs)**	21.11 3.6%	**R-Squared**	0.795

ESPAM Calibration Charts
Spring Flows

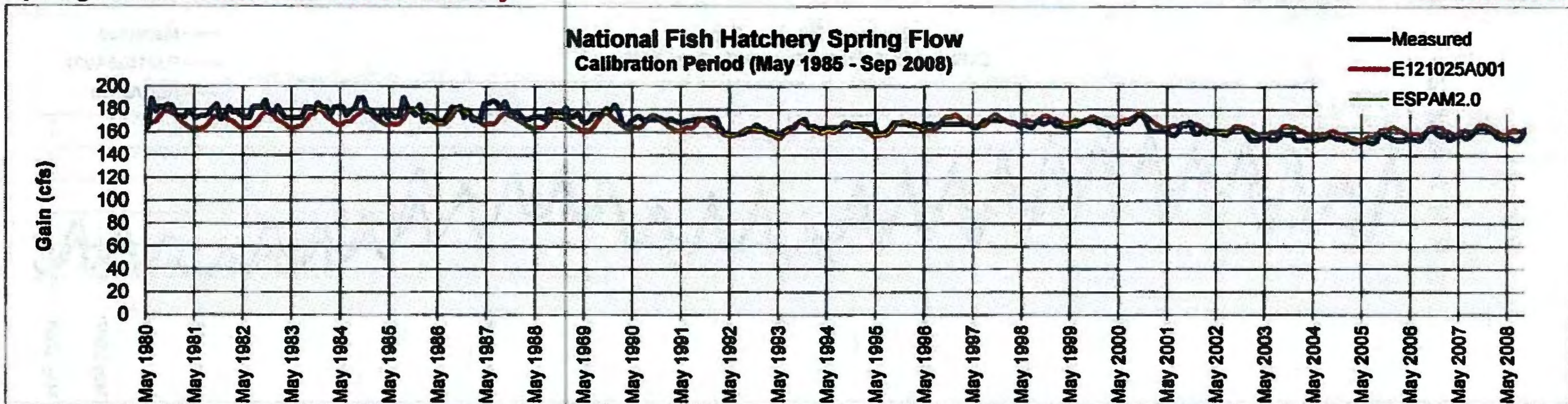
Spring Flows **Thousand Springs** **ESPAM2.1** **E121025A001**

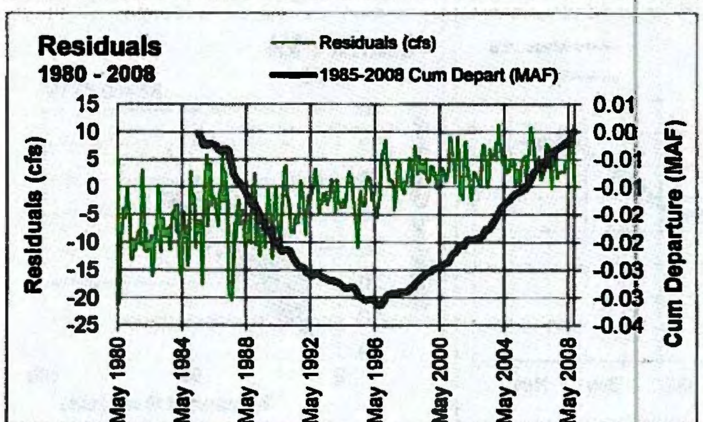


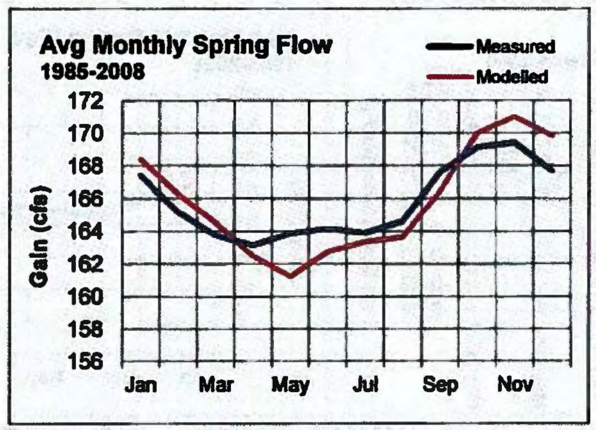
Mean Error (cfs)	0.36	Mean Absolute Error (cfs)	23.23	R-Squared	0.506
	0.1%		4.2%		

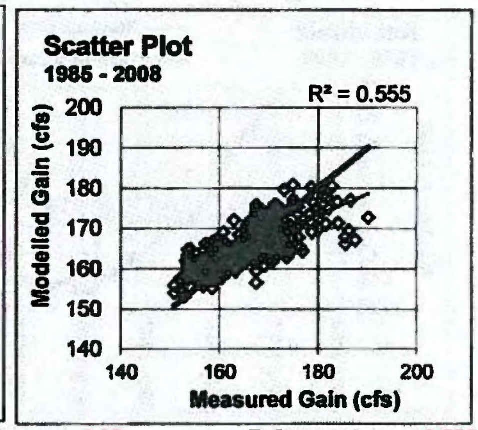
ESPAM Calibration Charts
Spring Flows

Spring Flows **National Fish Hatchery** **ESPAM2.1** **E121025A001**





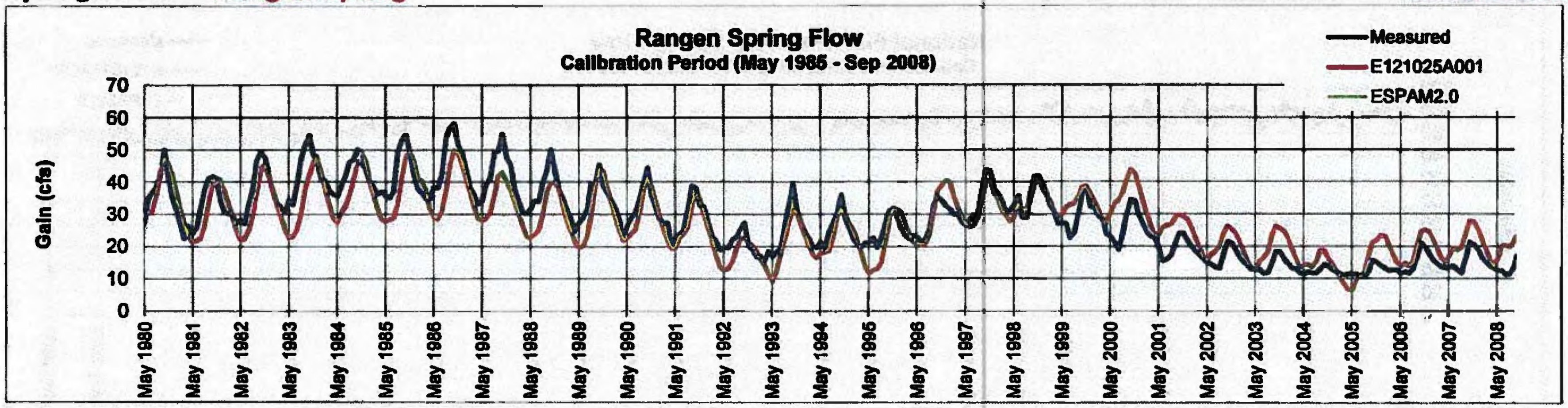


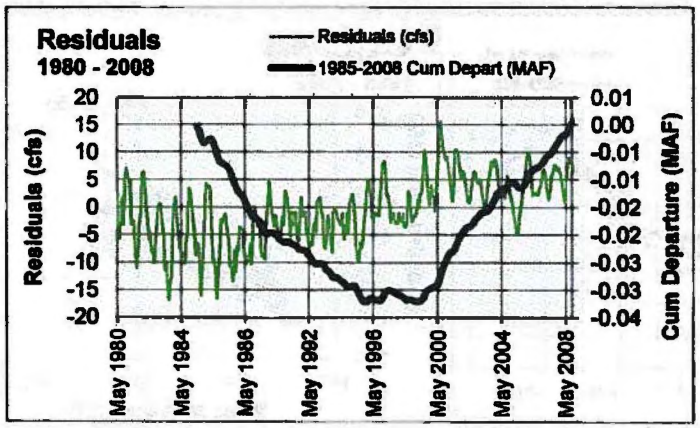


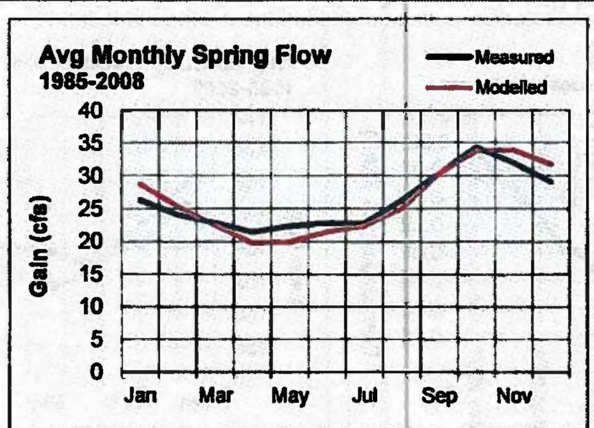
Mean Error (cfs)	0.00 0.0%	**Mean Absolute Error (cfs)**	4.25 2.6%	**R-Squared**	0.555

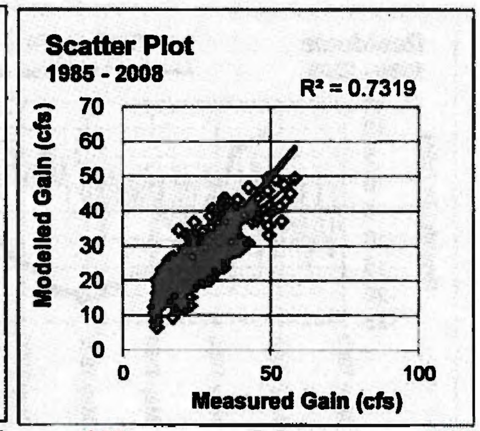
ESPAM Calibration Charts
Spring Flows

Spring Flows Rangen Spring **ESPAM2.1** E121025A001





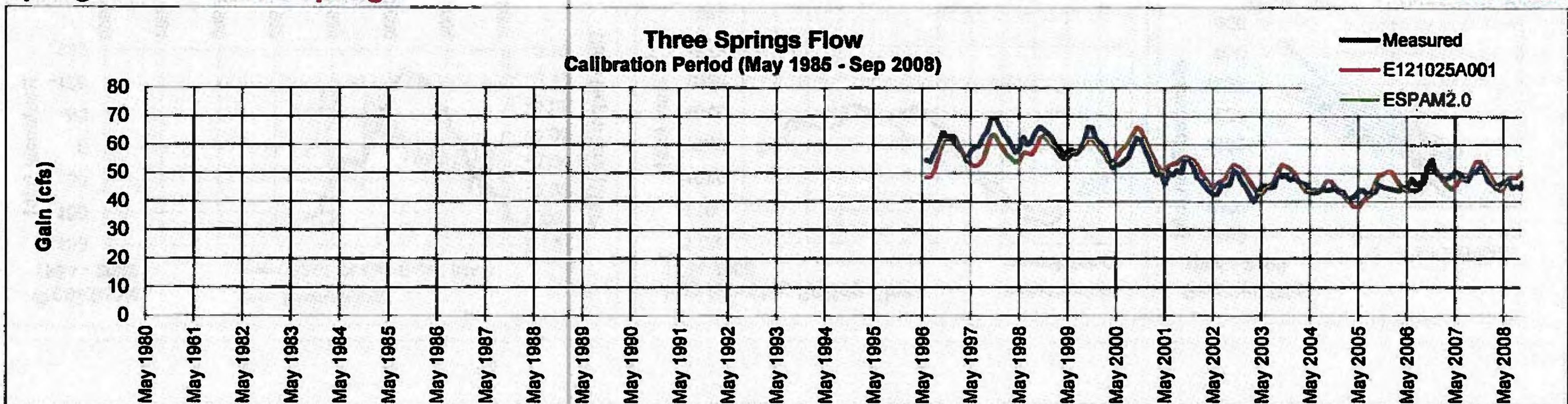


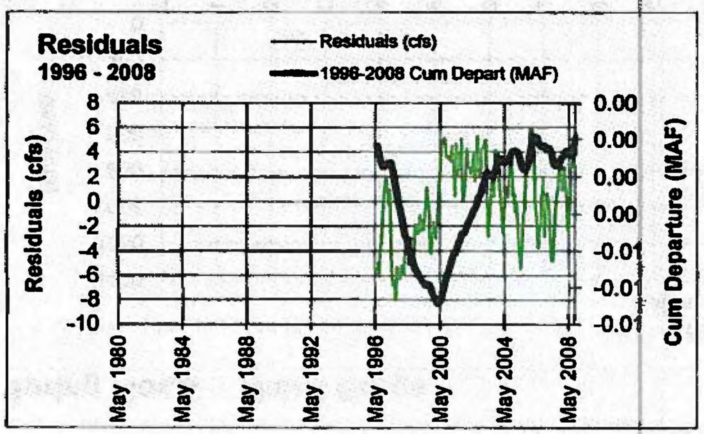


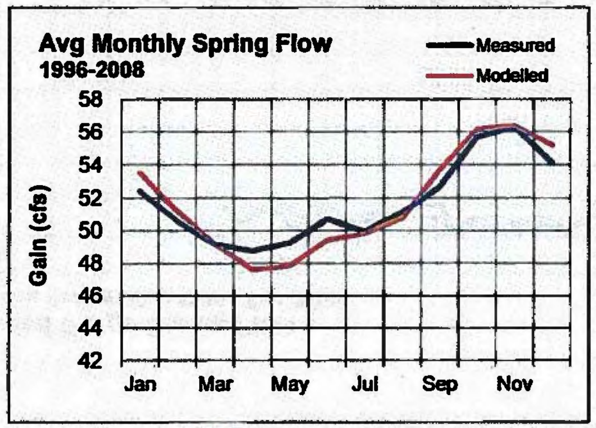
Mean Error (cfs)	0.04 0.2%	Mean Absolute Error (cfs)	4.57 17.4%	R-Squared	0.733

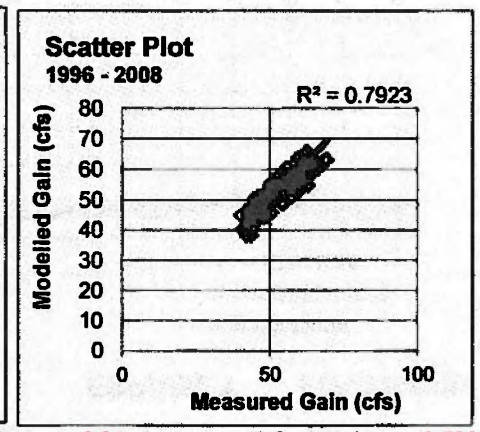
ESPAM Calibration Charts
Spring Flows

Spring Flows **Three Springs** **ESPAM2.1** **E121025A001**





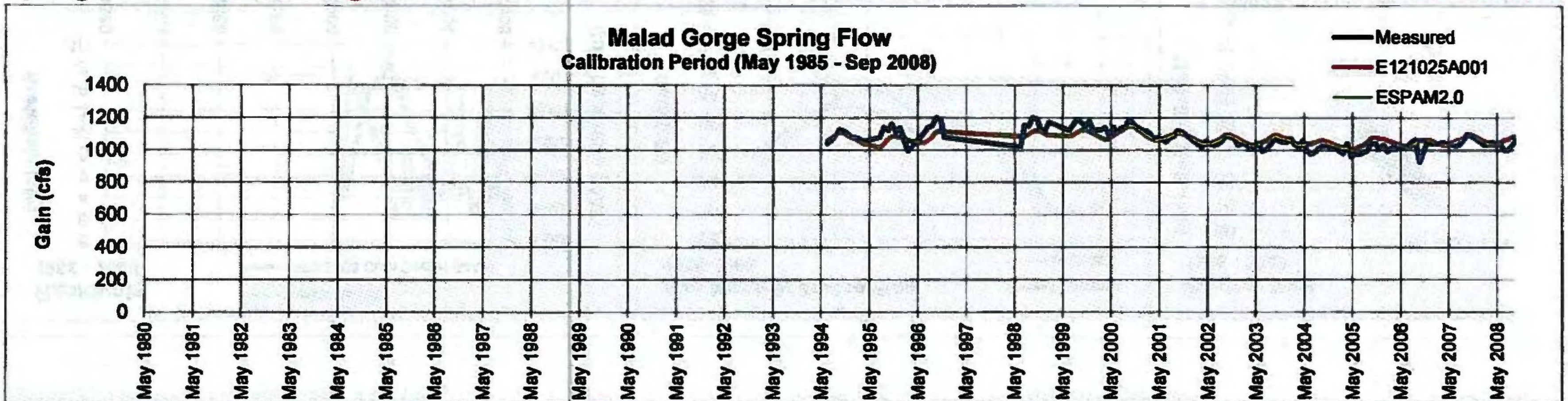


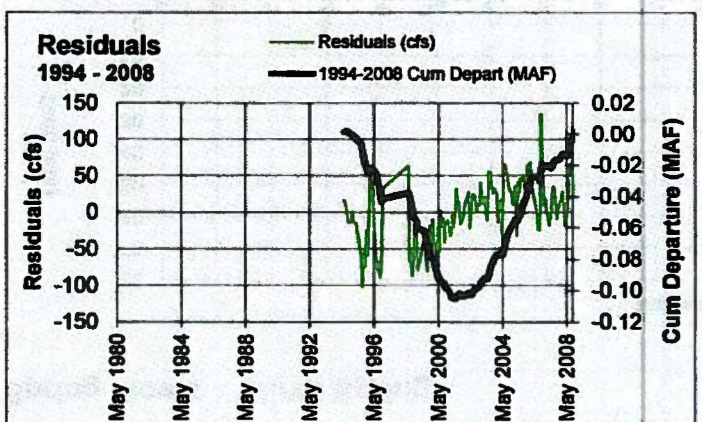


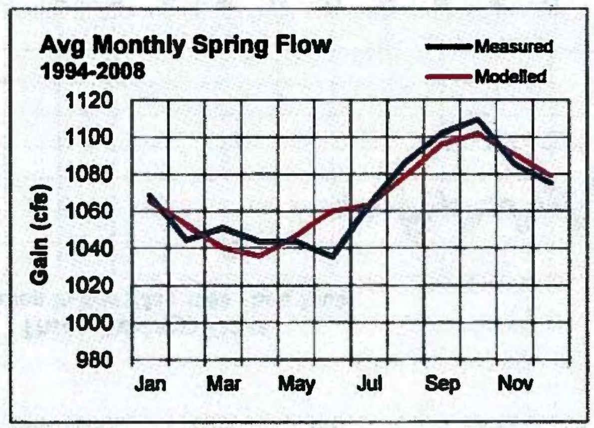
Mean Error (cfs)	0.02	Mean Absolute Error (cfs)	2.84	R-Squared	0.792
	0.0%		5.5%		

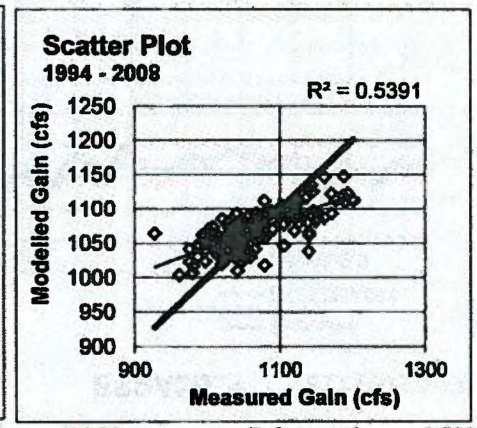
ESPAM Calibration Charts
Spring Flows

Spring Flows **Malad Gorge** **ESPAM2.1** **E121025A001**







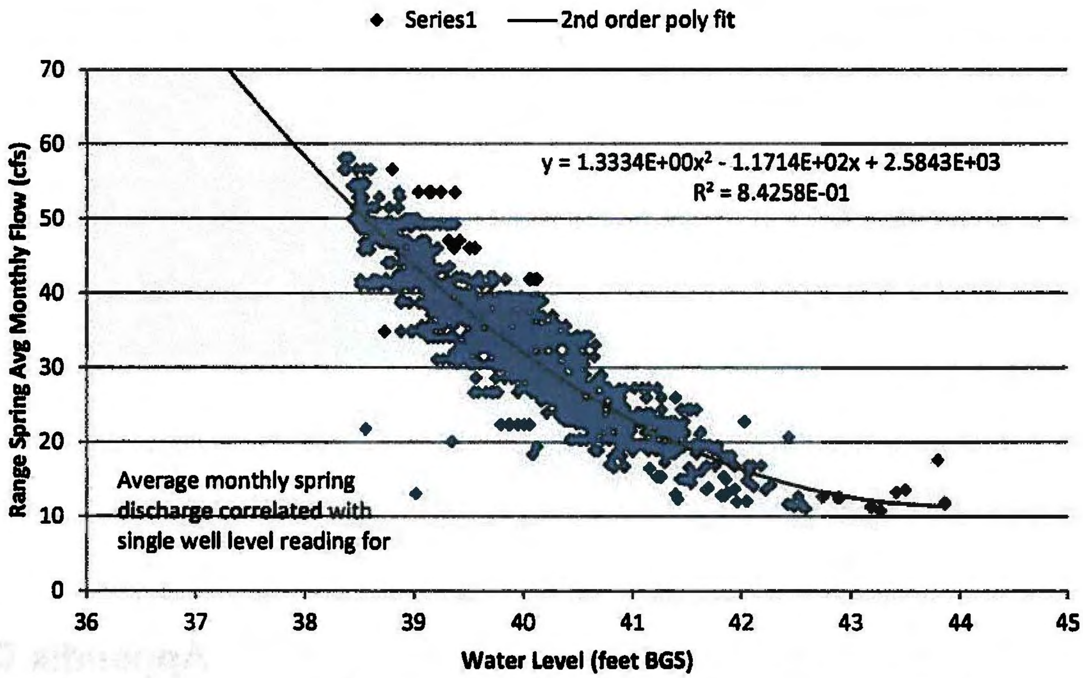


Mean Error (cfs)	0.23	Mean Absolute Error (cfs)	31.93	R-Squared	0.539
	0.0%		3.0%		

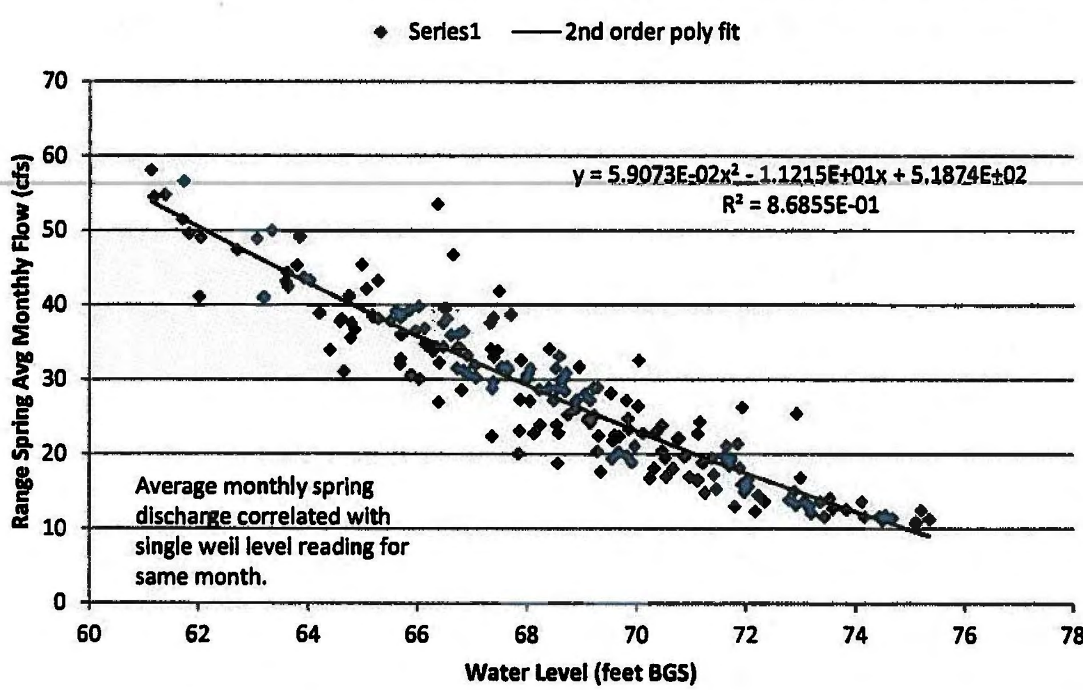
Appendix C

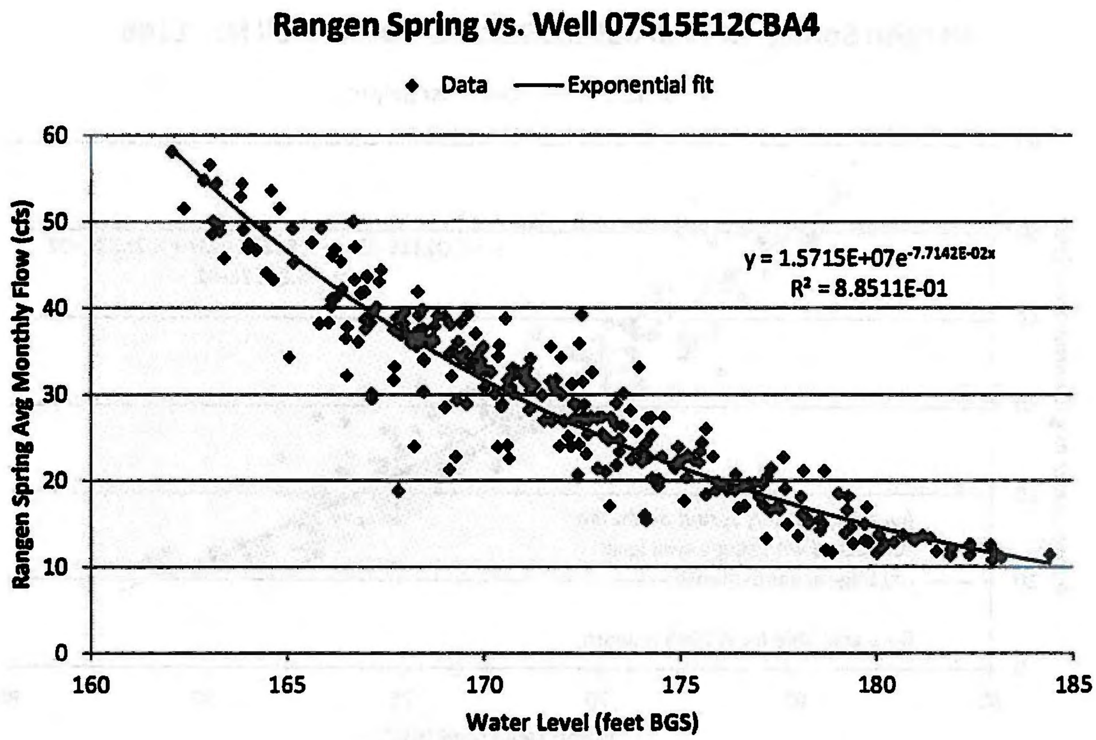
Development of Relationships between Groundwater Levels and Rangen Spring Discharge and map of Candidate Wells

Rangen Spring vs. Well 08S14E16CBB1

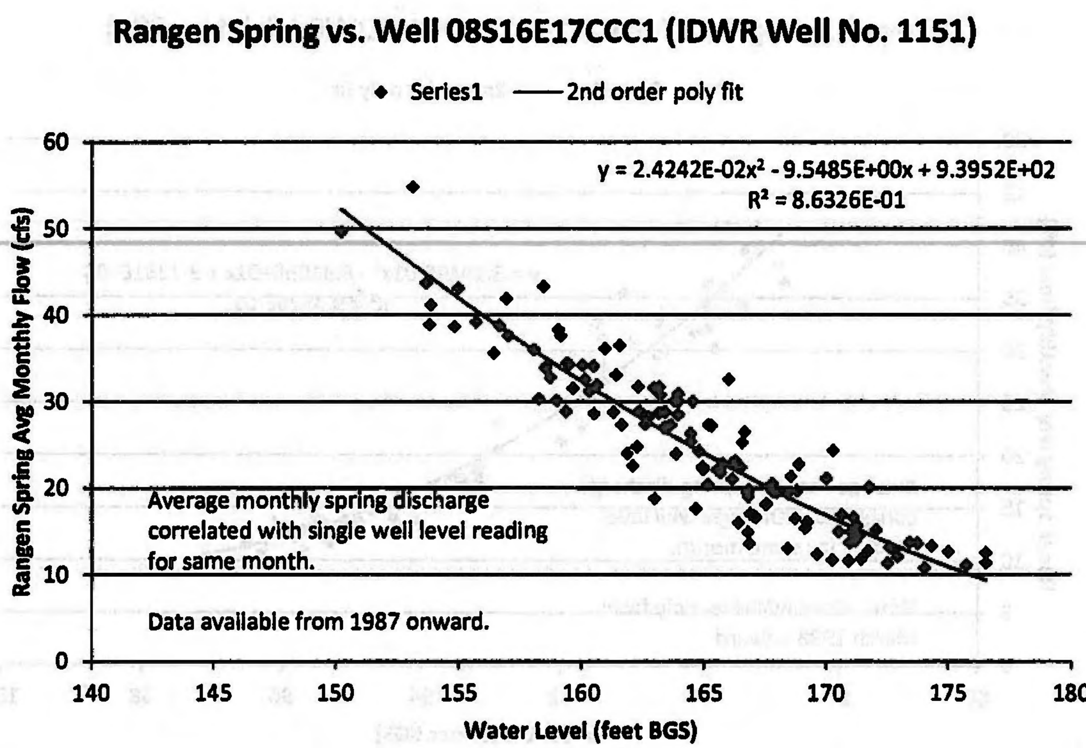


Rangen Spring vs. Well 08S14E12CBC1

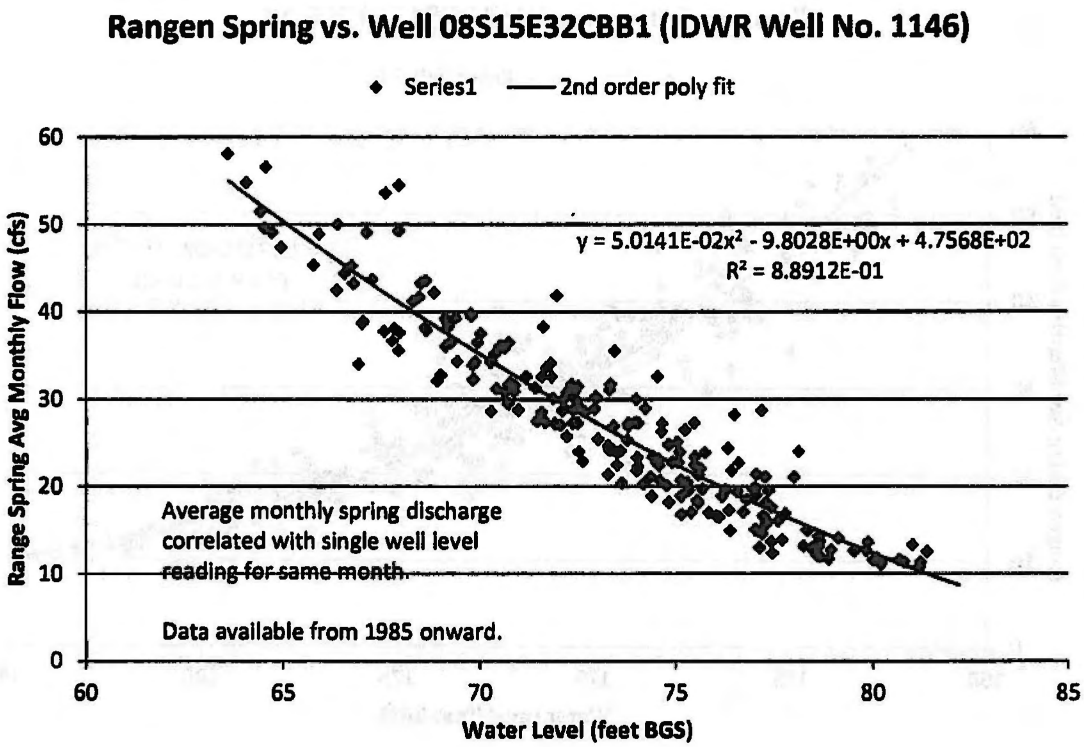


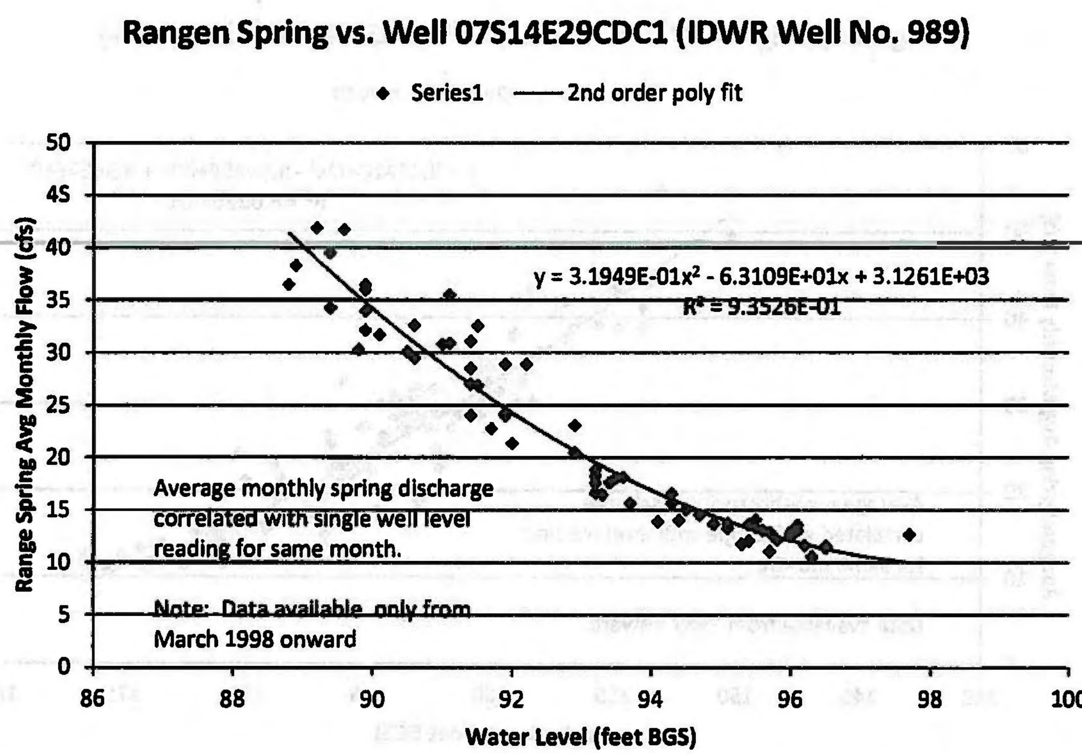


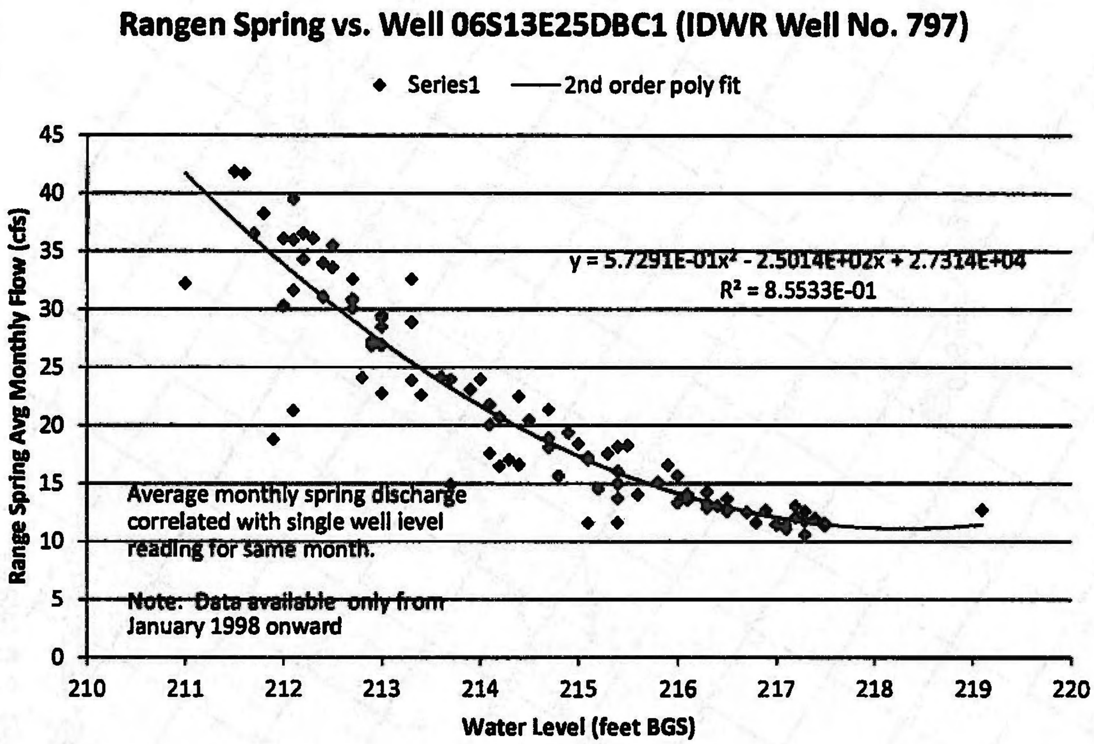
Rangen Spring vs. Well 07S15E12CBA4
Data
Exponential fit
y = 1.5715E+07e-7.7142E-02x
R² = 8.8511E-01
Rangen Spring Avg Monthly Flow (cfs)
Water Level (feet BGS)

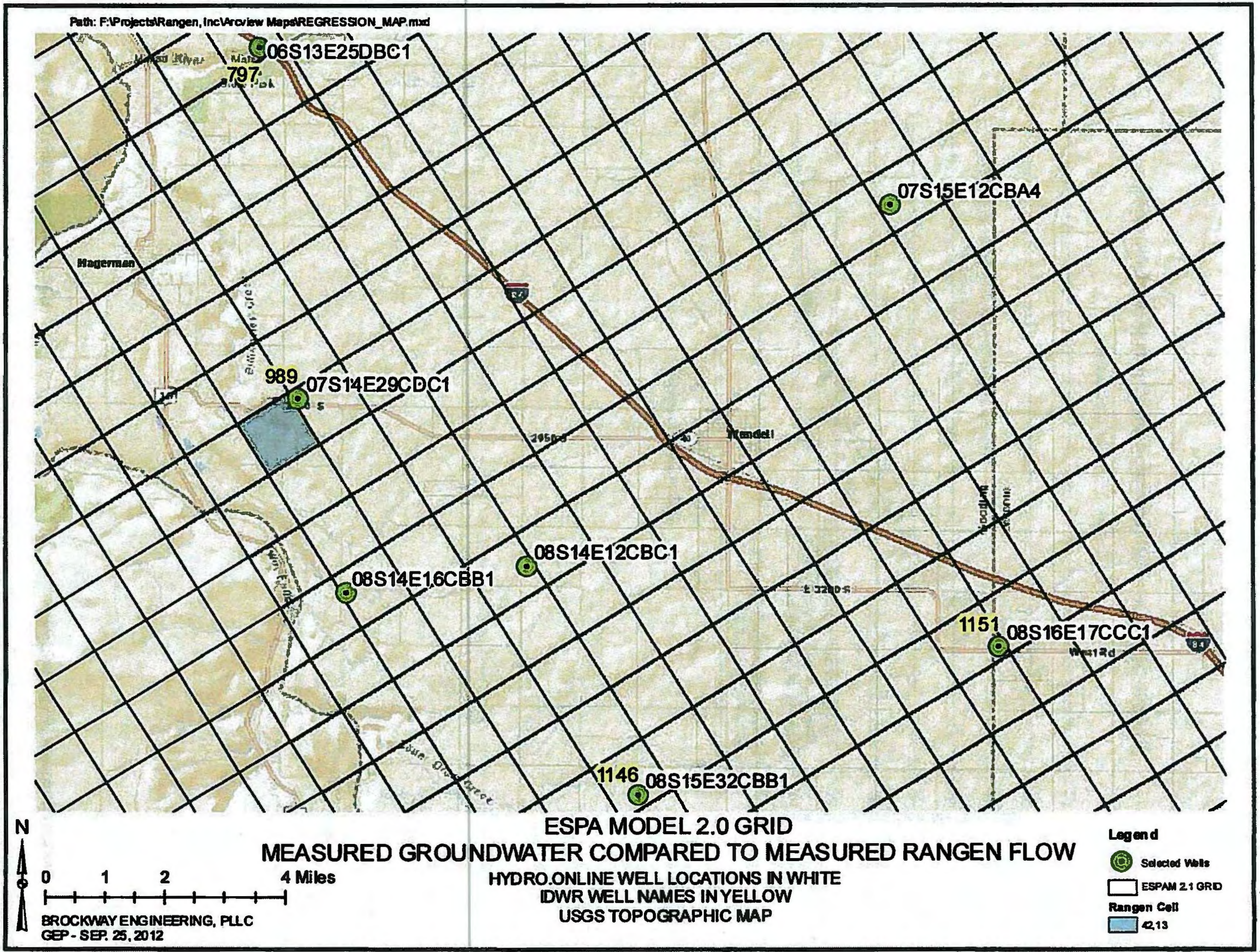


Rangen Spring vs. Well 08S16E17CCC1 (IDWR Well No. 1151)
Series1
2nd order poly fit
y = 2.4242E-02x² - 9.5485E+00x + 9.3952E+02
R² = 8.6326E-01
Average monthly spring discharge correlated with single well level reading for same month.
Data available from 1987 onward.
Rangen Spring Avg Monthly Flow (cfs)
Water Level (feet BGS)


Rangen Spring vs. Well 08S15E32CBB1 (IDWR Well No. 1146)
Series1
2nd order poly fit
y = 5.0141E-02x² - 9.8028E+00x + 4.7568E+02
R² = 8.8912E-01
Average monthly spring discharge correlated with single well level reading for same month.
Data available from 1985 onward.
Range Spring Avg Monthly Flow (cfs)
Water Level (feet BGS)
60
50
40
30
20
10
0
60
65
70
75
80
85


Rangen Spring vs. Well 07S14E29CDC1 (IDWR Well No. 989)
Series1
2nd order poly fit
y = 3.1949E-01x² - 6.3109E+01x + 3.1261E+03
R² = 9.3526E-01
Average monthly spring discharge correlated with single well level reading for same month.
Note: Data available only from March 1998 onward
Range Spring Avg Monthly Flow (cfs)
Water Level (feet BGS)
50
45
40
35
30
25
20
15
10
5
0
86
88
90
92
94
96
98
100


Rangen Spring vs. Well 06S13E25DBC1 (IDWR Well No. 797)
Series1
2nd order poly fit
y = 5.7291E-01x² - 2.5014E+02x + 2.7314E+04
R² = 8.5533E-01
Average monthly spring discharge correlated with single well level reading for same month.
Note: Data available only from January 1998 onward
Range Spring Avg Monthly Flow (cfs)
Water Level (feet BGS)
0
5
10
15
20
25
30
35
40
45
210
211
212
213
214
215
216
217
218
219
220



ESPA MODEL 2.0 GRID

MEASURED GROUNDWATER COMPARED TO MEASURED RANGEN FLOW

HYDRO.ONLINE WELL LOCATIONS IN WHITE

IDWR WELL NAMES IN YELLOW

USGS TOPOGRAPHIC MAP

APPENDIX C
Table 3 Rangen Spring Discharge vs. Aquifer Water Levels for Seven Nearby Wells

Summary-Analysis of Water level vs Rangen Spring Flow
Brockway Engineering, PLLC December 2, 2012
Regression Analysis See atached map for well locations
Average Monthly Rangen Spring Discharge vs Single Well Elev. Same Month

Well Number	Type of Fit	R^2
08S14E16CBB1	2nd order poly	0.8426
08S14E12CBC1	2nd order poly	0.8686
07S15E12CBA4	Exponential	0.8851
08S16E17CCC1	2nd order poly	0.8633
08S15E32CBB1 IDWR #1146	2nd order poly	0.8891
07S14E29CDC1 IDWR #989	2nd order poly	0.9353
06S13E25DBC1 IDWR #797	2nd order poly	0.8553
	Average	0.8770

Project No. 1159-01-2011 and 1179MSB01

Rebuttal Report in the Matter of Rangen Inc. - Availability of Spring Flow and Injury to Water Rights

Prepared for:

Rangen, Inc.

February 8, 2013

PROFESSIONAL ENGINEER
REGISTERED
1696
02/08/2013
STATE OF IDAHO
CHARLES E. BROCKWAY

Charles E. Brockway, Ph.D., P.E. Brockway Engineering

David Colvin, P.G. Leonard Rice Engineers David C. Colvin, P.G.

Jim Brannon, Brannon Developments

EXHIBIT
1299
CM-DC-2011-004

Exh. No. 123
Date 2/20/13
Name Brendecke
M & M Court Reporting

Exhibit D

Introduction

Expert reports on the water call by Rangen Inc. were submitted by Charles Brendecke of AMEC, Bern Hinckley and Thomas L. Rogers for the Idaho Ground Water Appropriators, Inc. (IGWA) and by Gregg Sullivan of Spronk Engineers for the City of Pocatello.

This report responds to various assertions in the reports by Brendecke, Sullivan, Spronk and Hinckley. A separate report addresses comments by Bryce Contor.

Specifically, we assert that the water rights issued by IDWR for the Rangen facility and the administration of those define and treat the entire Rangen Spring as a single source. The historical water measurement data, upon which the determinations of impacts from junior ground water pumping are determined and which were utilized for ESPAM 2.1 model calibration are correct.

~~The operation of the Rangen facilities for aquaculture research and fish production are consistent with the standard of care in the industry and the diversion facilities are reasonable, hydraulically adequate, and approved by IDWR. Multiple uses of the spring resource within the Rangen facility enhances water use efficiency and prevents operational waste within the system.~~

The geologic framework of the Rangen Spring is not anomalous compared to other springs emanating from the ESPA in the Thousand Springs area and the hydrogeologic conceptual model of the spring as modeled by IDWR with the ESPAM2.1 model is consistent with the known geology and ground water modeling protocols. Hypothetical interpretations of the Rangen Spring geology offered by IGWA consultants Hinckley and Brendecke are not justified and different conceptual models, as proposed by IGWA consultants, are incorrect. The total Rangen spring source, the Martin-Curren Tunnel outflow and the spring outflow through the talus, as developed for the Rangen water supply and authorized by valid State water rights, is the regional ESPA and should be modeled as such.

These expert reports can be characterized as a sudden reversal of a decade of open and collaborative ESPAM model development led by IDWR and with the cooperation and oversight of the members of the ESHMC, including Brendecke and Sullivan.

The ESPAM 2.1 ground water model is the best tool available for evaluation of responses and impacts to the ESPA from changes in water use. This model has been fully and adequately calibrated and validated by IDWR and the development guided and evaluated by the ESHMC, the members of which are eminent and qualified ground water modelers, hydrologists, and engineers.

The calibration of the ESPAM 2.1 ground water model utilized measured historical spring flow as targets to allow the automated calibration software, PEST, to obtain the best-fit (minimum sum of squares of deviations) of the simulated output and water levels in the ESPA. Rangen Spring historical calibration period discharge was a target in the PEST calibration. All of the Director's requirements for IDWR adoption of ESPAM2.1 have been met. These requirements include model calibration, validation, uncertainty analysis and comparison to ESPAM1.1.

Modification of the ESPAM 2.1 model to unilaterally reflect alleged differences in local geology without evaluation of impacts on other springs in the system is not justified. The utilization of alternative ESPA models, reflecting only differences in local geology of one spring with re-calibration of the modified model is not justified. The ESPA aquifer is a coherent hydraulically interconnected water body and manipulation of individual components (springs) without regard to the impact caused by re-distribution of flow through the aquifer is not justified and does not provide other water users any opportunity to evaluate impacts on their water sources.

IGWA consultants developed what they termed alternative ESPA models, the alternatives being changes to the geology of Rangen Spring, including simulation of a hydraulic barrier one or two miles long, down gradient of the Rangen Spring model cell, assumption of two separate springs within the Rangen Spring cell, addition of head target data, and arbitrary weighting of the importance of the more recent measured Rangen Spring total flow in the calibration process. There were apparently at least eight (8) different model configurations which were evaluated prior to selection of a representative alternative model. Results and documentation of alternative models #3 and #8 were the only model data provided for evaluation. Simulation runs using ESPAM2.1 and the two alternative models show that there is essentially no difference in the impact of curtailment of junior pumping to mitigate for impacts to the June 15, 1962 Rangen water right using the three models. Any differences between the simulated impact on Rangen Spring of curtailment using the alternative models and ESPAM2.1 are the result of application and manipulation of a trimline.

These expert reports introduce new and unvetted ideas, data, analyses and assertions in an inappropriate venue where they can neither be utilized nor explored objectively. They provide incomplete data for their "alternative models" without sufficient explanation as to why some results are included and others are not. And all of the "alternative model" curtailment scenario results are post-processed with the so-called "trimline" procedure, an arbitrary process for excluding data that is a non-scientific, administrative procedure that is inappropriate to introduce into groundwater modeling discussions and essentially renders the results useless and incomparable the standard IDWR curtailment modeling scenarios.

Our analysis of these reports and the alternative models presented concludes that they do not contradict the efficacy of IDWR's calibrated ESPAM 2.1 for quantifying the impact of junior well pumping on model boundary spring flows such as Rangen Spring. Quantifying these impacts is one of the key reasons ESPAM was developed and was used as a guiding objective during ESPAM calibration and uncertainty analyses. In fact, if the "alternative models" are used with the trimline post-processing filter removed, they actually reinforce the accuracy and robustness of the IDWR ESPAM 2.1 model.

As a result these reports have no impact on our opinion that the IDWR ESPAM 2.1 is still the best science available for understanding and quantifying the impacts of junior well pumping on spring flows tributary to the ESPA. IDWR should continue to use ESPAM 2.1 to estimate the reduction in spring flows at

Rangen Spring due to junior ESPA well pumping. Furthermore, the open and collaborative model (ESPAM2.1) that has worked so well should continue to be used. The alternative modeling and hydrogeology ideas and data should be introduced into the ESHMC as previous efforts have done, where it can be vetted and utilized constructively to enhance the ESPAM system.

The best estimate of the impact of junior pumping on Rangen Spring is the unmodified output from ESPAM 2.1. Utilization of a trimline of any percentage magnitude, justified by an unsubstantiated estimate of ground water model uncertainty, arbitrarily limits the true hydraulic impact of junior pumping and is not hydraulically or statistically supported. There has never been an uncertainty analysis performed on ESPAM2.1 or any ESPA ground water model to support the use of a trimline as currently configured.

B. Water Measurement Adequacy, Water Rights, SRBA Decreed and Permit Points of Diversion

The historical flow measurements made by Rangen personnel at the facility have been done correctly ~~and are accurate and adequate for the purposes for which they have been used,~~ including the historical 1980-2008 Rangen Spring complex flows for the IDWR ESPAM 2.1 calibration efforts.

~~The operation of the Rangen facilities for aquacultural research and fish production are consistent with the standard of care in the industry and the diversion facilities are reasonable, hydraulically adequate, and approved by IDWR. Multiple use of the spring resource within the Rangen facilities enhances water use efficiency and prevents operational waste within the system.~~

Brendecke criticizes Rangen's flow measurement accuracy with a statement that is extracted from the memo by Cindy Yenter to Karl Dreher (December 15, 2003). The statement was based on Ms. Yenter's site visit on November 24, 2003 during which she compared Rangen's reported flows in the CTR and Large raceways with measurements which she and Brian Patton took on the day after the flows were measured by Rangen. Ms. Yenter reported that the Rangen measurements on the previous day were 10% to 12% lower than her measurements. Ms. Yenter reported that she did not actually observe the Rangen employee measuring the flow in the CTR and Large raceways, but attributed the likely difference to the error caused by the use by Rangen employees of a metal 2 inch wide ruler to measure the head on the weir as compared to a standard staff gage. If a 'standard staff gage' as used by Ms. Yenter it is a Leopold and Stevens enamel Type C staff gage, 2.5 inches wide as compared with the 2 inch wide metal ruler used by Rangen. Use of a gage of different width to "stick" a weir or, in this case, the flow over dam boards, is highly unlikely to cause a 10% to 12% difference in calculated discharge. Table 5-4 from Brater and King (967) and included in Appendix A shows the calculated error in discharge for various sized weirs as a result of errors in measurement of the head. The weir boards on the Rangen CTR raceways for measurement of discharge are, on average, about 2 inches wide. When a staff gage or ruler is used to measure the head on a weir, the bottom of the gage is placed on the upstream edge of the board and turned so that the velocity of overflow causes the water surface to 'run up' on the gage. This maximum 'run up' is measured to account for the velocity head. The difference in 'run up' on a 2 inch wide gage as compared with the 'run up' on a 2.5 inch wide gage cannot be more than 0.01 feet. This run up is equal to the velocity head over the boards as calculated by the formula, $hv=v^2/2g$ where hv is the velocity head, v is the overflow velocity, and g is 32.2 ft/sec^2 or gravity. The over flow velocity for average heads of 0.4 ft as measured on the CTR boards is less than 2 ft/sec and the calculated velocity head, hv, is less that 0.06 ft. It is therefore not likely that the error or difference in heads measured using a 2 inch wide ruler versus a 2.5 inch staff gage would be as much as 0.01 feet. The difference in discharge, if the 'error" in staff gage reading is 0.01 ft, would therefore be less than 4 percent and not 10 to 12 percent. Ms Yenter indicates that Brian Patton applied the Francis formula individually to each set of data which included different widths of boards on each raceway and measurements of head at three points across the width of the boards. It is significant that flow measurements over 2 inch wide boards violates the assumption on which the Francis formula is based. Standard weir formulas assume a sharp crested weir is in place and not a 2 inch thick board. Studies conducted on flow over check boards at the ends of raceways on aquaculture facilities indicate that the weir coefficient that should be used for flow over check boards, is near 3.09 as compared to the standard Francis formula, which assumes a sharp crested weir with a coefficient of 3.33 (USBR Water Measurement Manual, 1967). King and Brater, (Appendix A) 1967 compiled research on broad crested weir coefficients which shows a weir coefficient for use on a broad crested weir of approximately 2 inch width of 3.08. This would be applicable to flow over check boards with heads between 3 and 4.5 inches. This difference in weir coefficients between the standard suppressed rectangular weir with C=3.33 and the more appropriate 3.09 results in a difference of 8%. The Rangen discharge table comports with a weir coefficient of about 3.08 (BCB report)

Sullivan also indicates that the memorandum from Cindy Yenter to Karl Dreher of December 15, 2003 contained "insufficient information as to fully understand why IDWR concluded that the Rangen staff was under-measuring the flows through the hatchery raceways". This conclusion is warranted. In fact, the statement by Ms. Yenter is based on comparison by IDWR staff of one measurement of flow through the Large raceways not made on the same day as the measurement reported by Rangen staff. The comparison is flawed also because IDWR staff utilized the discharge rating curve for a standard sharp crested weir when in fact the flow was over dam boards, which is best represented by a modified weir coefficient resulting in a discharge rating similar to that utilized by Rangen personnel.

Sullivan also indicates that the difference in measured flow from the Martin-Curren Tunnel, which IDWR began measuring in 1993, and the total flow through the hatchery is the flow that originates below the tunnel. This is an incorrect observation in that, the flow from the Martin-Curren Tunnel flows into a concrete box from which several irrigation pipes convey part of the flow to irrigation interests or to the hatchery. Depending on the level of discharge from the tunnel, any excess flow from the box overflows into the talus slope and appears as flow at the toe of the slope and has not originated below the tunnel. Any calculation of the 'flow originating below the tunnel' utilizing this assumption is incorrect. So, Sullivan's assertion that Martin-Curren Tunnel flows averaged 40 percent of the total Rangen flow during 1993-2011 and 30 percent of the total Rangen flow since 2001 is likely in error.

Utilization of monthly average flow data to evaluate whether or not there was or could be beneficial use of a water right neglects the shorter term fluctuations in discharge which are characteristic of all springs in the Thousand Springs area. For instance, Sullivan indicates (P12, Sullivan Report) that the reported monthly average flow in April 1977 was 35.2 cfs and this is far less than would have been necessary to supply any portion of Rangen' April 12, 1977 priority water right. However, the model calibration data set as shown as utilized by IDWR shows values higher than 35.2 cfs during 1977. 1977 was the lowest single year flow record in the Snake River basin and this is reflected in the 1977 and 1978 flow records for most springs emanating from the ESPA.

Sullivan's analysis of Rangen Spring Flow records and estimates of water utilization from the Spring source implies that, in order for beneficial use to be effected, the total water right must be present at all times and must be utilized in some part of the facility to meet some beneficial use criteria. Figure 4-10 which Sullivan has compiled shows Total Unused Flow as compiled from monthly Idaho Power Hatchery Production Summaries and Total Rangen flow reported by Rangen and Martin-Curren Tunnel flow reported by IDWR. The assumption was that the Unused Total Flow is equal to the Total Rangen Flow minus the greater of the flows measured in the (Troughs plus Small Raceways), Large Raceways or CTR Raceways. This assumption implies that any water available from the source at any time that does not flow through a production facility is, in fact, unused or not beneficially used and is therefore a measure of inefficiency or waste. ~~This assumption reflects an un-familiarity with the operation of aquaculture facilities which require periodic harvesting and movement of stock within the facility which results in temporary non-use of specific raceways or rearing facilities.~~

Use of the historic flow measurement data collected by Rangen staff are accurate for water rights analysis and for the development of ground water model calibration targets.

C. Facilities operations, Diversions, Multiple Use, and Waste within System

~~Historic IDWR water rights administration and ESPAM2.1 modeling treat the Rangen Spring flow as a~~ single spring source that includes Martin-Curren Tunnel and lower talus spring discharge. ~~The Rangen diversion structures effectively deliver the available water for use in the facility, where it is put to efficient use according to standard aquaculture practices.~~

The Martin-Curren Tunnel issues from the basalt comprising the upper member of the Glenns Ferry formation. The tunnel was excavated nearly horizontal into the basalt in order to enhance existing spring flows. This construction is similar to the construction of the many ganats or karezes which have been in use for hundreds of years in Pakistan, Afghanistan, Iraq, and Iran and across the arid regions of southwestern Asia. The horizontal tunnel intercepts the sloping water table, providing a hydraulic gradient toward the tunnel and induces additional flow out of the tunnel. This was and is a standard procedure which has been utilized to develop and enhance flow from various major springs issuing from the ESPA (Crystal Springs, White Springs, Hoagland Tunnel). The impetus by early irrigators (1884-1908) to enhance the existing spring by excavating the Martin-Curren Tunnel was the presence of a significant amount of flow from the spring at or near the elevation of the tunnel mouth. Current geologic evaluations and interpretations are not adequate to conclude that the Martin-Curren Tunnel outflow is separate from the flows emanating from the lower talus slope. Idaho Code 42-230b states the definition of a well as, "Well' is an artificial excavation or opening in the ground more than eighteen (18) feet in vertical depth below land surface by which ground water of any temperature is sought or obtained. There is no statutory definition of a "horizontal well". The water rights for the source of water for the Rangen facility are decreed as springs and not a well or wells.

Capture of water from the stream just downstream from the talus slope (headwaters of Billingsley Creek) would require pumping into the small raceways and then re-use of the pumped water in the large raceways ~~causing oxygen depletion in the large raceways~~. There is no indication in any of the beneficial use exams conducted by IDWR for any of the Rangen water rights that the diversion system is inadequate or unreasonable. To our knowledge, there are no aquaculture facilities on springs issuing from the ESPA that utilize pumping for primary water supplies. ~~The risk of pump failure is too high and, even though the concept may be hydraulically feasible, the risk and water quality degradation has not been deemed a feasible alternative by the commercial trout industry.~~

Pumping water out of Billingsley Creek into the small raceways and thence into the Large Raceways ~~would result in water quality impacts on available Large Raceway and CTR Raceways and~~ would require interruptible electrical power, which represents a risk to the reliability of continuous flow through the raceways. ~~The fact that use of pumped water for commercial aquaculture is not utilized in the Thousand Springs area indicates that the industry realizes the risks involved with this type of source and has opted not to utilize pumped water.~~

D. Geologic Interpretations and Conceptualization

Brendecke and Hinckley present hypothetical geologic interpretations as the basis for ESPAM2.1 conceptual changes. The geologic data they rely on are generally too sparse and uncertain to provide clear and convincing evidence in support of their concepts. Furthermore, much of the geologic information has little bearing on the modeling of impact to the Rangen Spring caused by junior ground water pumping. Hinckley presents three main geologic interpretations and implies that they are controlling factors on the influence of ground water pumping on spring flow. Three concepts he puts forth are hypothetical concepts of the base of the Quaternary basalts, a reinterpretation of the potentiometric surface, and a concept that the eastern rim of the Hagerman Valley acts as a barrier to ground water flow.

These hypothetical concepts, while adding locally significant complexity, do very little to change the major regional aquifer behavior observed and accurately simulated by the calibrated IDWR ESPAM 2.1. Even though they may influence locally ground water flow direction and rates they are not the primary controlling factors on the relationship between regional ground water pumping and Rangen Spring discharge.

The USGS recently published a circular aimed at correcting common misconceptions about depletion caused by ground water pumping (Barlow and Leake, 2012). In this publication, the authors identify four misconceptions, one of which is described as, *"Misconception 2. Depletion is dependent on the rate and direction of water movement in the aquifer."*

The fundamental hydrogeologic principals controlling depletion of the Rangen Spring flow are that:

Widespread ground water pumping causes a regional decline in aquifer head;

Regardless of ground water flow direction or velocity, head declines caused by pumping propagate as pressure changes;

Head decline or pressure change propagation is controlled by aquifer properties of transmissivity and storage coefficient. These properties create large regional areas that affect discharge of springs in the Thousand Springs area, including Rangen Spring.

When evaluating the depletion caused by large areas of pumping within the ESPA, the aquifer properties are dominated by horizontal propagation of stresses. Because of this, depletion caused by ground water pumping is accurately and appropriately modeled by ESPAM2.1 as a single layer, confined aquifer.

The USGS summarizes these points:

"The independence of depletion and rates and directions of groundwater flow in most systems allows calculation of depletion by a number of different methods. These methods include analytical solutions, superposition models, and groundwater-flow models (see "Analytical and Numerical Modeling" section). In using either analytical solutions or superposition models, the natural rates and directions of groundwater flow are ignored." (Barlow and Leake, 2012)

The sources of data cited by Brendecke (Farmer, 2009 and 2011) show that the hydrology of the subsurface indicates aquifer material that creates large areas of contribution to the Thousand Spring area spring discharges. These large areas of contribution are the primary controls on the interaction between junior pumping within the areas of contribution and the spring discharge rates. Furthermore, it is these highly complex features referenced by Brendecke that interconnect the primary aquifer of the ESPA.

When he presents his interpretation of the bottom of the Quaternary basalts, Hinckley uses it to define the bottom of the "primary aquifer". He acknowledges that there is some flow within the Tertiary sedimentary layers and basalt layers. He presents geologic data indicating high transmissivity in the upper part of the Tertiary basalts. While describing localized geologic conditions, Hinckley summarizes them in his Figure 8. Hinckley describes the data on this figure in the following way:

> *"Contouring distant from control points and in areas with only "less-than" control points is hypothetical, presenting an interpretation consistent with the available data, but more conceptual than precise." (Hinckley, 2012)*

The "less-than" control points Hinckley refers to are 11 wells up to 14 miles away from Rangen where the well does not reach the bottom of the Quaternary basalt, and yet Hinckley uses these wells to plot the bottom of the Quaternary basalt. West of Rangen, the vast majority of Hinckley's data are these "less-than" control points and are not appropriate, accurate, or reliable data for this sort of interpretation. His hypothetical representation of the subsurface calls into question all of the conclusions based on it and does not represent clear and convincing evidence of the "highly localized conditions" repeatedly referenced by Brendecke and Hinckley.

Hinckley further misrepresents the influence of the local geology on Rangen Spring flows when he discusses the available ground water level data. On page 13, Hinckley states,

"Groundwater flow directions on this and other figures in this report are inferred based on perpendicularity to equal-head contours. In basalt aquifers, this generalization is more appropriate over larger areas than at very local scales." (Hinckley, 2012)

This is a true statement and is supported by the tracer study work presented by IDWR tracer study results (Farmer and Blew, 2011). Localized groundwater flow in the basalt dominated ESPA is controlled by preferential flow through localized high transmissivity zones. Additional complexities may be added by faults that can act as either preferential flow paths or barriers. The data available in the area of the Hagerman Rim are too geographically sparse to determine the influence of these localized conditions. ESPAM2.1 appropriately approximates the hydrogeology as a regional system that is interconnected by all of these locally complex flow features. Hinckley supports this claim with his statement:

"Although data density in the area is insufficient to delineate local gradients in detail, the contouring of Figure 16 offers an interpretation that is more consistent with the available data than previous mapping." (Hinckley, 2013)

Hinckley's Figure 16 relies on a subset of the IDWR November 2011 synoptic sampling data (IDWR, 2012). The reason to perform a synoptic sampling is to have one comprehensive data set that is collected at the same time by one team of scientists collecting the data. This approach allows for greater quality control and continuity of hydrologic conditions during the data collection. In his reinterpretation of the synoptic data, Hinckley selectively removed water levels that he interpreted to be from a deeper, disconnected aquifer. He then added in additional data points collected at different time periods. Two measurements were within 2 months of the synoptic sampling, and one measurement from 4 years prior. Inclusion of the data point from 4 years prior is particularly problematic and inappropriate because the data from this well shows variability and decline in water levels (IDWR hydro.online, 2013).

In support of his theory that the Hagerman Rim is a barrier to ground water flow, Hinckley describes the Hagerman Rim as a "westward termination of groundwater flow". It would be more accurate to state that the Hagerman Rim is the location where ground water discharges through the rim as spring flows. The Hagerman Rim does not restrict subsurface flow anywhere where there are Quaternary Basalts, transmissive Tertiary sediments, or transmissive Tertiary basalts are near the rim. Current and historic spring locations are evidence of this. A rise in ground water head would cause more water to flow out of the Hagerman Rim. Anecdotal evidence (personal communication with Frank Erwin, June 21, 2012) indicates that many more springs existed near Rangen in the past.

As supported by Hinckley's statements and the available data inappropriately used in his report, the localized geologic complexity in the Rangen area cannot be accurately resolved. Furthermore, this localized complexity contributes to the connection between the Rangen Spring and its' regional area of influence, the ESPA. Section E.2. of the BCB report presents the analysis of the relationship between regional water levels and Rangen Spring flows supports the connection of the regional ESPA to the Thousand Springs area. These objective, measurable data refute the hypothetical theory put forth by Hinckley that localized geologic features disconnect Rangen Spring flows from the impacts of regional ground water pumping.

E. ESPAM 2.1(Development, ESHMC, Adequacy, Calibration)

ESPAM2.1 is the culmination of decades of ESPA ground water research and model development. The ESHMC has provided guidance and oversight to create an open environment for fair and technically sound model development. The model objectives are best summarized by the IDWR modelers in their final report.

"A primary objective of the model development and calibration was the characterization of the interaction between the aquifer and the river. Although thousands of aquifer water level observations were used during the model calibration, the model was optimized for prediction of hydrologic impacts to the river and to Group A and B springs. The model can be used to provide a general sense of groundwater to groundwater impacts; however, the model is best used for prediction of impacts to surface-water resources resulting from regional groundwater use or from changes in the magnitude, timing, and spatial distribution of aquifer recharge." (IDWR, 2012)

ESPAM 2.1 adequately simulates the outflow of the spring system at Rangen which includes flow from the Martin-Curren Tunnel and the remaining flow emanating from the talus slope the total of which is the source of water for the Rangen water rights. It is not necessary to 'separate' the individual flows since they both originate from the regional system and are included in the source for the SRBA decreed water rights.

Spring discharge is affected by changes in water use by surface water entities including conversions to sprinkler irrigation from surface irrigation, ground water pumping for irrigation, and variations in irrigation water requirements over the ESPA. These affects are regional perturbations in the net flux or input to the ESPA and all springs emanating from the ESPA respond to these changes. The input data set to the ESPAM 2.1 model incorporates these temporal changes and the model simulated output reflects these regional impacts and changes in water budget. These man-made temporal changes in water use do not impair the use of ESPAM 2.1 to simulate impacts to Rangen Spring due to junior ground water pumping.

Constant model thickness and constant transmissivity are model assumptions accepted by the ESHMC as a necessary simplification of the natural system. Accepting this does not preclude the usefulness of model results. The high quality of model predictions at the Rangen Spring is evidence that the model is appropriately conceptualizing the regional water system that contributes to the flow conditions at the springs.

ESPAM2.1 has a large number of parameters, which is by design, and approved by the ESHMC. A large number of parameters does not equate to increased likelihood that the model is not unique, especially if specific calibration techniques are employed. ESPAM2.1 was calibrated using PEST automated calibration software and a powerful technique that allows for (and even encourages) the use of a large number of parameters. Large numbers of parameters and the procedures used during ESPAM2.1 calibration are common practice when using PEST to calibrate groundwater models.

ESPAM2.1 was designed to predict total Rangen Spring flows and cannot differentiate the Martin-Curren Tunnel. The IDWR modelers and the ESHMC are considering changing some of the ESPAM springs from one drain to two drains.

Brendecke makes the statement, "ESPAM2.1 simulates conditions that are not physically possible and conditions that are in direct opposition to observed conditions..." This is unjustified and a dramatized textual attempt to skew the reader's opinion of ESPAM2.1. The claim of impossibility of ESPAM2.1 simulated conditions is unjustified and an over exaggeration of the required and commonly accepted modeling practice of simplifying assumptions. Hinckley and Brendecke provide no data to support the claim that ESPAM2.1 is in direct opposition to observed conditions. The use of the words "direct opposition" is not a scientifically sound description.

Relative to the other springs, the Rangen Spring flow predictions are both accurate and precise. In the 1980-2008 calibration period, the mean difference between the observed and modeled Rangen Spring flows is reported as 0.04 CFS with a mean absolute error of 4.57 CFS. We discuss identified inaccuracies with the lower flow predictions in our report in section C.5. ~~of our report.~~

A thorough evaluation of uncertainty does involve other components in addition to a predictive component. The predictive component attempts to quantify the range of specific simulated output as a result of allowing calibration within a specific range of the objective function. As outlined in the expert report of Brockway, Colvin and Brannon (BCB report), the result of the IDWR predictive uncertainty analysis, proposed by Doherty, the author of the PEST program, does provide a measure of the calibrated model's ability to simulate output within a reasonable range of the objective function. The best estimate of the simulated output is the result from the calibrated model for which PEST has minimized the objective function. Changing hydrogeologic parameters at specific locations to prevent "improper conceptualization" of geologic and hydraulic conditions is speculative at best and should not be conducted arbitrarily without a thorough model-wide evaluation of all parameters. IDWR decided, and the ESHMC agreed, that a full uncertainty analysis which would likely involve a Monte Carlo approach was not achievable and not mandatory. Changing the geologic parameters and configuration in ESPAM2.1 for a particular spring without evaluating all other spring configurations and recalibrating would not be justified.

Alternative conceptual models could be proposed providing that adequate evidence exists to justify alternative concepts. However, any proposed alternative model should be vetted and receive a thorough review and approval by qualified hydrologists and ground water modelers before being utilized for administrative purposes.

The AMEC alternative models further support that the ESPAM2.1 is a robust model and that using any of the models above to evaluate full ESPA curtailment show virtually identical results for Rangen Spring flow impacts. Put another way, the non-unique models created by AMEC come up with the same predictions. As further demonstrated by Brendecke's work, it is the arbitrary application of a "trimline" that results in different predictions. This further illuminates the non-technical and problematic nature of a "trimline".

F. AMEC Alternative Models and Curtailment Analyses

Brendecke has developed alternative models to test the impact of conceptual and calibration changes to ESPAM2.1. These changes are based on the hypothetical concepts put forth by Hinckley and have not been vetted in an open, collaborative environment such as the ESHMC.

Improving the ESPAM to better reflect geologic complexity is an effort that IDWR and the ESHMC are currently addressing. In doing so, the IDWR modelers and the ESHMC are weighing the benefits of adding complexity to the ESPAM based on available data. When enough clear and convincing data are not available to guide a conceptual model, a modeler is required to make assumptions.

Alternative calibrated models, as defined by Brendecke, include hydraulic barriers to east-west ground water flow patterns, not substantiated by indisputable hydrologic and hydraulic evidence; weighting of arbitrary segments of the calibration spring discharge data set, and reconfiguration of the drain cell treatment in an attempt to reflect multiple aquifer sources for which adequate evidence is lacking. One could arbitrarily configure the spring hydrogeologic parameters so that curtailment would beneficially produce almost any percentage of curtailed depletion. Utilization of an arbitrary 10% trimline or any trimline is not justified since use of the trimline, which is model specific, drastically reduces the defined curtailment area within the common ground water boundary. Use of a 10% trimline with ESPAM 2.1 reduces the contributing irrigated area to Rangen Spring from ground water pumping to 406 acres out of a potential 479,199 potentially curtailed acres within the common ground water boundary on the ESPA. Similarly, the potential curtailed discharge within the common ground water boundary on the ESPA to the Rangen July 1962 priority water right is estimated at 17.13 cfs. (IDWR Rangen Scoping). Utilization of a 10% trimline reduces the curtailed discharge to 0.19 cfs within the 406 acre curtailed area or 1.1% of the common ground water ESPA discharge from junior ground water pumping. This arbitrary reduction to only 1.1% of the junior ground water pumping affecting the Rangen Spring cannot be justified hydrologically or hydraulically and can only be justified by a desire to minimize the required mitigation for impact to the Rangen water rights.

ESPAM 2.1 was configured (number of drain cells and calibrated elevation) in a manner similar to all other A &B springs in the Devil's Washbowl to King Hill reach of the Snake River. The decision to utilize one drain within the model cell representing Rangen Spring was made by IDWR and reviewed by ESHMC because geologic data and information indicates that a two-drain configuration is not warranted. The purpose of utilizing two-drain configurations is not necessarily because there is geologic evidence to support two different spring sources but to allow PEST more latitude to better simulate the range of measured spring flow over the calibration period.

It should be noted that ESPAM 2.1 has been calibrated with measured total spring discharge ranging from over 50 cfs to just over 10 cfs or a range of about 40 cfs. This range in measured and simulated response is an adequate range to support predictive simulations required for evaluation of curtailment or other mitigation measures. Simulations of impacts from the Rangen water call using ESPAM2.1 predict an impact of up to 18 cfs for curtailment of the July 12, 1962 water right over the entire aquifer. This simulated change in spring flow is not "radically different from those extant in the model calibration period" so the ESPAM 2.1 model can be expected to represent and predict accurately the expected behavior of the aquifer and springs due to this magnitude of flux change. Brendecke (p 6-8) concludes that "Relatively minor changes in ESPAM2.1 conceptualization, made to more closely reflect the local conditions at Rangen, result in model predictions that differ substantially from those of ESPAM2.1." The proposed 'minor changes in model conceptualization' are not in any sense minor.

Table 6.1 of Brendecke's report shows what he characterizes as "...model predictions that differ substantially from those of ESPAM2.1." This table shows the comparison of ESPAM2.1 and two alternative models which predict the impact of curtailment using the unjustified and technically inappropriate "trimline". The spring flow predictions presented in Table 6.1 range from 0.01-0.21 cfs. These flow amounts would be extremely difficult to measure in the field and are very likely under the predictive precision of the model. Brendecke's statement that his alternative model produces 5% of the ESPAM2.1 result is misleading. The change is small in volume, and the result was primarily due to the number of acres curtailed. The alternative model curtailed 24 acres compared to 406 acres curtailed using ESPAM2.1. In addition, model runs using Brendecke's alternative model showed virtually no difference from ESPAM2.1 predictions of Rangen Spring flow when using a full ESPA curtailment. The alternative model presented by Brendecke actually further verifies that the ESPAM2.1 model is an accurate and appropriate predictor of impacts to Rangen Spring flow from regional junior ground water pumping.

The alternative models proposed by Brendecke confirm the results of ESPAM 2.1. Table 1 shows the results and comparison of curtailment model runs utilizing ESPAM 2.1 and alternative Models #3 and #8. All three of the models were run to determine the simulated impact on Rangen Spring from curtailment of ground water rights in the ESPA junior to July 13, 1962, IDWR procedures and protocol were use for all three model runs with the models run in steady state and superposition model. Table 1 indicates that the steady state response at Rangen Spring not significantly different for any of the three models. If anything, the ESPAM 2.1 model is conservative in its prediction of the curtailment response to Rangen.

Table 1 July 13, 1962 superposition, steady state, full curtailment results from ESPAM 2.1, AMEC-3, and AMEC-8

Model	Steady State Response at Rangen (cfs)
ESPAM 2.1	17.9 cfs
AMEC-3	18.5 cfs
AMEC-8	18.0cfs

Determination of selected contributing model cells for the alternative models illustrate the irrational nature of arbitrarily eliminating model cells from inclusion in the contributing aquifer area for springs.

Table 2 shows a comparison of response functions to Rangen (Cell No. 42, 13). Model cells listed were identified by IDWR as the contributing model cells to Rangen Springs for Scoping Calculations evaluated for ESPAM 2.0. Cells with a more than 0.5% change in the response functions as determined by the different models are highlighted.

Table 2 Response of Rangen Spring to Pumping at Various Model Cells (Response Functions)

Model Cell	ESPAM 2.1	AMEC-3	AMEC-8
40, 13	9.5%	9.7%	9.5%
41, 13	10.5%	10.7%	10.4%
41, 14	9.5%	9.7%	9.5%
42, 12	11.6%	8.2%	10.1%
42, 13	16.0%	15.9%	15.5%
42, 14	10.7%	10.8%	10.5%
43, 13	9.5%	9.1%	9.1%

Table 2 shows that only one model cell (42, 12) shows a significant difference in the percentage of contribution from any of the seven model cells identified by IDWR as contributing cells. Cell 42, 12 is the cell down-gradient of the Rangen Spring and down-gradient of the hydraulic barrier inserted in alternative models #3 and #8 by Brendecke. Again, there is no basis for the selection of non-contributing cells proposed as the 10% criteria for exclusion was identified by IDWR for ESPAM 1.1 because of potential errors in the Snake River Gage readings.

Therefore, when the AMEC alternative model output is taken as a whole (with and without the application of a trim line), it actually indicates that it is only the trim line method that has an unacceptably large arbitrary and uncertain behavior, and it indicates that the ESPAM 2.1 base model is robust and stable in terms of the relationship between pumping stresses and spring flows. All the alternative model output provided by AMEC used a trimline. When compared to ESPAM 2.1 output using a trimline, Brendecke showed wide variations in the results. However, this is an artifact of a trimline approach that excludes all but a tiny fraction of the original model results. As commonly known by engineers and scientists, comparing two very small numbers at the limits of the precision of the system can create an appearance of variability and uncertainty. On the other hand, as shown above, when comparing the full AMEC alternative model output to the full ESPAM 2.1 model output without a trimline, there is still very good agreement on the impacts of junior pumping on Rangen Spring flows.

IDWR (Sukow, 2012) performed an evaluation of model linearity and the appropriateness of using a superposition model.

"The superposition version of the model is expected to be acceptable for simulation of curtailment of groundwater pumping, managed recharge, most ESPA water right transfers, and mitigation activities including conversions from groundwater to surface water irrigation, the Conservation Reserve Enhancement Program (CREP), and voluntary reductions in irrigation." (Sukow, 2012)

IDWR compared five different curtailment scenarios, including one with a 1/1/1961 curtailment date. They found that the difference between superposition ESPAM2.0 curtailment models and those using a fully populated model were less than 1% for the spring flow predictions. This is an indication that the non-linearity issues raised by Brendecke do not adversely affect the accuracy of the spring flow predictions and that curtailment modeling using a superposition model is appropriate.

G. Unjustified Application of the "Trim Line"

Use of any statistical parameter to limit the result of a ground water model simulation, if not justified by some recognized statistical parameter and applied in a defensible manner should not be considered. Brendeke and Sullivan consistently utilize what might be termed a one-way exclusion parameter (trimline) to limit the liability of junior ground water pumpers for mitigation of impacts to the Rangen water rights. This one-way exclusion parameter assumes that no junior ground water pumping which does not impact the Rangen Spring flow by 10% or more at steady state is not, in fact, impacting the Rangen Spring flow. Not only is the concept of a 'trimline' not hydraulically justified, the arbitrary assignment of a 10% exclusion limit is not justified by any statistically recognized procedure and certainly not by any rigorous statistical uncertainty analysis. We are not aware of any statistics textbook or publication which even mentions the term 'trimline'.

To infer or conclude that any deferred pumping as a result of curtailment of junior ground water pumping that does not benefit the calling spring or target spring is 'waste' implies a short-sighted view of the ESPA system. Granted that target curtailment for mitigation is not efficient, however, the deferred pumping impact that shows up in adjacent springs or as Snake River reach gain is not 'wasted'. All springs and reach-gains in the ESPA/Snake River system have shown declines over the last 50 years and most of these sources either have water rights for irrigation, aquaculture, hydropower, or aesthetic, recreation, and wildlife purposes. Supplies for these water rights have been impacted; any increases in these sources can be beneficially utilized and are therefore not 'wasted'.

Brendecke's assertion that the 'uncertainty derives from use of a regional model to predict discharge from a particular spring outlet at the edge of the aquifer system' is an erroneous assumption. ESPAM2.1 is a regional model and calibration of target springs shows that it is capable of adequately simulating spring flow responses from regional changes in water use (Appendix B, BCB report). Correlations of Rangen Spring historical discharge and other target springs with individual wells as much as 11 miles away exhibit excellent correlation coefficients (R^2) (Appendix C, BCB report). Measured seasonal discharge and testimony of the Watermaster and Rangen employees attest to the seasonal response of the springs to the commencement and cessation of irrigation on the Northside Canal lands and to ground water pumping up-gradient of the springs.

H. Conclusions and Recommendations

The overarching conclusion of this report is that nothing presented in the AMEC, Spronk, or Hinckley reports, refutes ESPAM2.1 as being the best available science for the evaluation of junior ground water pumping impacts at the Rangen Spring. The results of ESPAM2.1 modeling indicate that a full ESPA curtailment of junior ground water pumping would be a hydrologically feasible mitigation of the impact to Rangen Spring.

Nothing presented in the aforementioned reports changes the opinions originally presented in our BCB report. Our opinions contained in this report are summarized as follows:

1. Pumping by junior ground water rights impacts the exercise of Rangen water rights 36-02551 (priority July 13, 1962) and 36-07694 (priority April 12, 1977).
2. ~~There is insufficient spring flow available to operate the Rangen facility and that the available Rangen Spring flows are being utilized appropriately and efficiently according to the adjudicated water rights. There is no evidence of wasted water.~~
3. Rangen staff historical measurements have been collected accurately.
4. Historical measurements are adequate for use as calibration target data for ESPAM2.1.
5. The source of ESPA water for Rangen's water rights includes flow from the Martin-Curren Tunnel and the talus slope below it.
6. Rangen's water rights are decreed as springs and not as a well or wells.
7. ~~Rangen's diversion structures are efficient and appropriate for aquaculture use of water.~~
8. ~~Use of water within Rangen's system is in accordance with standard aquaculture practices.~~
9. The geologic interpretations presented by Hinckley are not applicableapplicable when evaluating ESPAM2.1's ability to predict the impact of junior ground water pumping on the Rangen Spring.
10. The geologic interpretations of Hinckley are hypothetical and rely on sparse data which is inappropriately used in some cases.
11. ESPAM2.1 has been developed in an open and peer reviewed manner to have appropriate simplifications and assumptions that result in accurate predictions of the impact of junior ground water pumping on the Rangen Spring.
12. IDWR has appropriately designed ESPAM2.1 and that, according to IDWR model documentation, *"...the model was optimized for prediction of hydrologic impacts to the river and to Group A and B springs."* Rangen is a group B spring.
13. IDWR has demonstrated that the superposition version of ESPAM2.1 is accurate for curtailment scenarios and that there is very little difference in the superposition and fully populated model results.
14. The "trimline" has no technical justification and should not be applied.
15. The best estimate of impact of junior ground water pumping on the Rangen Spring is the unaltered output of ESPAM2.1.
16. The similarities between the results from alternative models presented by Brendecke and results from ESPAM 2.1 prove that ESPAM2.1 is a robust model. Even when inappropriate changes are made to the conceptualization of the model, it predicts virtually the same Rangen Spring response to full ESPA curtailment of junior ground water pumping.
17. The alternative model results also point out that it is the arbitrary and technically unjustified application of a "trimline" that causes variability in predictions of Rangen Spring flow impacts.

References

Barlow, P.M., and Leake, S.A., 2012, Streamflow depletion by wells— Understanding and managing the effects of groundwater pumping on streamflow: U.S. Geological Survey Circular 1376. (Also available at http://pubs.usgs.gov/circ/1376/).

Brendecke, C.M., 2012. Hydrology, Water Right and Groundwater Modeling Evaluation Of Rangen Delivery Call. AMEC Environment & Infrastructure

Brockway, C.E., Colvin, D.C., and Brannon, J., 2012. Expert Report in the Matter of Rangen Inc. - Availability of Spring Flow and Injury to Water Rights. Prepared for Rangen, Inc. December 20, 2012.

For Racine, Olson, Nye, Budge and Bailey. December 21, 2012, corrected January 17, 2013.

Farmer, N., 2009. Review of Hydrogeologic Conditions Located at and Adjacent to the Spring at Rangen Inc., Idaho Department of Water Resources Open File Report. March 4, 2009.

Farmer, N., 2009. Review of Hydrogeologic Conditions Located at and Adjacent to the Spring at Rangen Inc., Idaho Department of Water Resources Open File Report. March 4, 2009.

Farmer, N. and Blew, D., 2012; Fluorescent Dye Tracer Tests and Hydrogeology near the Malad Gorge State Park (Meyer, Conklin and Riddle wells); IDWR Open File Report.

Farmer, N. and Blew, D., 2012. Fluorescent Dye Tracer Tests and Hydrogeology near the Malad Gorge State Park (Hopper well test); IDWR Open File Report. January 28, 2011.

Hinckley, B., 2012. Rangen Groundwater Discharge and ESPAM2.1 Hydrogeologic Investigation. Hinckley Consulting For Racine, Olson, Nye, Budge and Bailey. December 21, 2012, with January 18, 2013 errata.

IDWR, 2012. Draft Enhanced Snake Plain Aquifer Model Version 2.1 Final Report; Idaho Department of Water Resources with guidance from the Eastern Snake Plain Hydrologic Modeling Committee.

IDWR hydro.online, 2013. http://www.idwr.idaho.gov/hydro.online/gwl/default.html; Accessed January 29, 2013.

King, Horace Williams and Brater, Ernest F., Handbook of Hydrologics, Fifth Edition, McGraw-Hill Company, New York, 1963.

Sukow, J., 2012a. Comparison of Superposition Model with Fully Populated Model for Eastern Snake Plain Aquifer Model Version 2.0, Idaho Department of Water Resources. July 18, 2012.

Sullivan, G.K., 2012. In the Matter of Distribution for Water to Water Right Nos. 36-02551 and 36-07694 (Rangen, INC.). Spronk Water Engineers, Inc. for the City of Pocatello. December 21, 2012.

USBR, 1967, Water Measurement Manual, Second Edition.

Appendix
Water Quality Monitoring of Billingsley Creek Head Water and Lower Tunnel Slope

HANDBOOK OF HYDRAULICS

for the Solution of Hydrostatic and Fluid-flow Problems

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where S is defined as follows:

$$S = \frac{a_2 \sqrt{H_2}}{a_1 \sqrt{H_1}} \qquad (5\text{-}52)$$

In Eq. (5-52), a_2 is the weir area corresponding to H_2 and a_1 is the weir area corresponding to H_1. Mavis also presented some interesting data which resulted from tests made in 1717 by Poleni. It was found that Poleni's results agreed within 2 to 4 per cent with the Mavis data.

The author has plotted the curves shown in Fig. 5-5 based on the results of the work of Villemonte and Mavis. Information regarding the experimental arrangements for the 90° V-notch weirs and rectangular weirs is given in the following table. It may be noted that the channel widths differed for the two

	Mavis	Villemonte		
Channel width........	4 ft 0 in.	3.02 ft		
P for 90° V-notch weirs	1 ft 6 in.	2.0 ft		
P for rectangular weirs	1 ft 10 in.	2.0 ft	1.0 ft	1.25 ft
Widths of notches of rectangular weirs...	1 ft 3 in.	3.02 ft	0.5 ft	1.00 ft

sets of tests, that P was different for all cases, and that rectangular weirs of four different widths were tested. Curves 1 and 2 are composite curves based on the results of the two investigators for the 90° V-notch weirs and the rectangular weirs, respectively. Curves 1 and 2 differ by no more than 1 per cent from the test results.

Because Eqs. (5-50) and (5-51) both indicate that Q/Q_1 is a function of $(H_2/H_1)^n$, the author has prepared curve 3, which is an average of results obtained from Eqs. (5-50) and (5-51). Results obtained from either equation differ by less than 1 per cent from curve 3. Curve 3 may be used to compute the discharge of a submerged sharp-crested weir of any shape. This curve is also in reasonable agreement with the results of the investigations summarized by Vennard and Weston, as well

as with data presented by Stevens.[1] It should be noted, however, that for some of the weirs tested, the results could be represented more closely by an equation differing slightly from Eqs. (5-50) and (5-51) and by a curve differing slightly from curves 1 to 3. Therefore, if great accuracy is essential, it is recommended that the particular weir, or a similar one, be tested in a laboratory under conditions comparable with field conditions. In using the curves shown in Fig. 5-5, it is recommended that H_1 be measured at least $2.5H_1$ upstream from the weir and that H_2 be measured beyond the turbulence caused by the nappe.

Example 5-4. Determine the discharge of a 90° V-notch weir if H_1 is 0.9 ft, H_2 is 0.3 ft, and $Q_1 = 2.5H_1^{2.5}$.

a. Use curve 1 of Fig. 5-5.

$$Q_1 = 2.5 \times 0.9^{2.5} = 1.92 \text{ sec-ft}$$

$$\frac{H_2}{H_1} = \frac{0.3}{0.9} = 0.333$$

$$\frac{Q}{Q_1} = 0.972 \text{ (from curve 1)}$$

$$Q = 0.972 \times 1.92 = 1.86 \text{ sec-ft}$$

b. Use curve 3 of Fig. 5-5.

$$\left(\frac{H_2}{H_1}\right)^n = (0.333)^{2.5} = 0.064$$

$$\frac{Q}{Q_1} = 0.972 \text{ (from curve 3)}$$

$$Q = 0.972 \times 1.92 = 1.86 \text{ sec-ft}$$

Example 5-5. Determine the discharge of a parabolic weir if H_1 is 0.8 ft, H_2 is 0.4 ft, and $Q_1 = 2.0H_1^{2.0}$.

$$Q_1 = 2.0 \times (0.8)^{2.0} = 1.28 \text{ sec-ft}$$

$$\left(\frac{H_2}{H_1}\right)^n = \left(\frac{0.4}{0.8}\right)^{2.0} = 0.25$$

$$\frac{Q}{Q_1} = 0.89 \text{ (from curve 3)}$$

$$Q = 0.89 \times 1.28 = 1.14 \text{ sec-ft}$$

Weirs Not Sharp-crested

Sharp-crested weirs, if used to obtain discharge records for comparatively long periods, are difficult to maintain. The

[1] J. C. Stevens, Experiments on Small Weirs and Modules, *Eng. News*, Aug. 18, 1910.

crest is likely to become dulled or rusted, or it may be damaged by floating ice and debris. Under such conditions it may be advisable to use a weir with a thicker crest. It is often convenient to use an existing weir or overflow dam for measuring discharges. Weirs of various dimensions and shapes are used in hydraulic structures. When designing such structures it is important to be able to estimate approximately the discharges over these weirs (p. 2-15).

The amount of water which will pass over a weir, not sharp-crested, depends to a large extent upon its sectional form and the shape of its crest, and it is necessary to resort to experiment to determine the discharge over any particular shape. Inasmuch as the number of shapes of weirs is unlimited, it is not to be expected that experimental data are or ever will be available for them all. There are available, however, the results of several series of experiments on weirs of different cross sections which furnish much valuable information for determining discharges over weirs of the same or similar shapes.

The available experiments are not extensive enough for a comprehensive study of the effect of velocity of approach on weirs not sharp-crested. The coefficients given in this chapter probably apply more accurately where the velocity of approach is not high. From a consideration of sharp-crested weirs it appears that discharges, for high velocities of approach, will be somewhat greater than is given by formula (5-10).

Since experimental conditions will seldom be duplicated in practice, it is probable that errors may result from the general use of the coefficients given in this chapter. Extreme accuracy, however, is not always necessary in design, where uncertainty as to the exact quantity of water to be provided for may exist.

The problem of establishing a fixed relation between head and discharge, for weirs not sharp-crested, is complicated by the fact that the nappe may assume a variety of forms in passing over the weir. For each modification of nappe form, there is a corresponding change in the relation between head and discharge. The effect of this condition is more noticeable for low heads.

The nappe may undergo several of these modifications in succession as the head is varied. The successive forms that appear with an increasing stage may differ from those pertaining to similar stages with a decreasing head. The head at which the changes of nappe form occur varies with the rate of

change of head, whether increasing or decreasing, and with other conditions.

Among weirs of irregular section there is a large class for which, from the nature of their section, the nappe can assume only one form unless drowned. Such weirs, it is suggested, may, if properly calibrated, equal or exceed the usefulness of the thin-edged weir for purposes of stream gaging, because of their stability of section and because the thin-edged weir is not free from modification of nappe form for low heads.

Broad-crested Weirs. A weir approximately rectangular in cross section is termed a broad-crested weir. Unless otherwise noted, it will be assumed to have vertical faces, a plane level

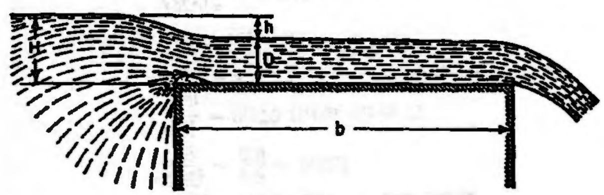


FIG. 5-6. Broad-crested weir.

crest, and sharp right-angled corners. Figure 5-6 represents a broad-crested weir of breadth b. The head H should be measured at least $2.5H$ upstream from the weir. Because of the sharp upstream edge, contraction of the nappe occurs. Surface contraction begins at a point slightly upstream from the weir.

The discharge over broad-crested weirs is usually expressed by the equation

$$Q = CLH^{3/2} \qquad (5\text{-}10)$$

Experiments on broad-crested weirs have been performed by Blackwell, Bazin, Woodburn, the U.S. Deep Waterways Board, and the U.S. Geological Survey. These experiments cover a wide range of conditions as to head, breadth, and height of weir. Considerable discrepancy exists in the results of the different experimenters, especially for heads below 0.5 ft. For heads from 0.5 to about 1.5 ft the coefficient becomes more uniform, and for heads from 1.5 ft to that at which the nappe becomes detached from the crest, the coefficient as given by the different experiments is nearly constant and equals approximately 2.63.

When the head reaches one to two times the breadth, the nappe becomes detached and the weir becomes essentially sharp-crested. The effect on discharge of roughness of the crest can be computed by applying the principles of flow in open channels.

In order to put the results of the various experiments in a form convenient for use, Table 5-3 has been prepared by graphically interpolating the results of all experiments, giving more weight to those of the U.S. Geological Survey. This table should give values of C within the limits of accuracy of the original experiments. Table 5-1 gives three-halves powers of numbers.

The effect of rounding the upstream corner of a broad-crested weir is to increase the discharge for a given head. Table 5-4 gives a résumé of experiments on this type of weir. The effect of rounding the upstream corner on a radius of 4 in. is to increase the coefficient C approximately 9 per cent. Coefficients by Woodburn[1] for flat weirs with rounded upstream corners and gently sloping crests are given in Table 5-5a.

Blackwell experimented with three weirs 3.0 ft broad having a slightly inclined crest. Inclining the crest appears slightly to increase the coefficient of discharge. The results of these experiments are rather inconsistent, especially for low heads. Table 5-5b has been obtained from Blackwell's experiments. Sloping the top of a broad-crested weir makes it similar to a triangular weir with the upstream face vertical. The coefficients given in Tables 5-6 and 5-7 will therefore be helpful in selecting coefficients for broad-crested weirs with sloping crests.

If the upstream corner of a weir is so rounded as entirely to prevent contraction, and if the slope of the crest is as great as the loss of head due to friction, flow occurs at critical depth, and discharge is given by the rational formula

$$Q = 3.087LH^{3/2} \qquad (5\text{-}53)$$

For further discussion of flow at critical depth, see Sec. 8. It should be noted that $C = 3.087$ is the maximum value of the coefficient that is obtainable for broad-crested weirs under any conditions.

Weirs of Triangular Section. Figure 5-7 represents the cross section of a weir having the upper face vertical and the lower

[1] J. G. Woodburn, Tests on Broad Crested Weirs, *Trans. ASCE*, vol. 96, 1932.

face inclined downward, the two faces meeting in a sharp angle which forms the crest.

Bazin has experimented with weirs of this type, 2.46 ft high, having various slopes of the downstream face. The coefficients resulting from those experiments are given in Table 5-6.

It will be observed that the coefficient for a given slope, in each case shown by the experiments, is nearly constant for heads above 0.7 ft. It seems fair to assume, therefore, that these values could be extended to higher heads with reasonable assurance. The average values of the coefficients given in

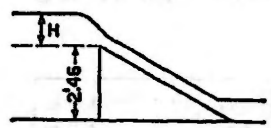


FIG. 5-7. Triangular weir.

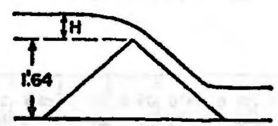


FIG. 5-8. Triangular weir.

Table 5-6, for heads above 0.7 ft, were plotted logarithmically and found to fall very accurately on a straight line. This line was then extended to include slopes of 20 horizontal to 1 vertical, from which the values given in Table 5-7 were taken. Table 5-7 may be used for computing discharges over weirs of the types shown in Fig. 5-7 for heads above 0.7 ft. These coefficients are to be used for broad-crested weirs with inclined tops only when the breadth is sufficient to prevent the nappe from springing clear. In the latter case the weir becomes in principle a thin-edged weir.

Bazin also experimented with weirs of triangular cross sections 1.64 ft high, having both faces inclined (Fig. 5-8). Coefficients covering the range of these experiments are given in Table 5-8.

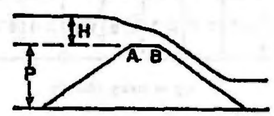


FIG. 5-9. Trapezoidal weir.

Weirs of Trapezoidal Section. Figure 5-9 represents a weir of trapezoidal section with both upstream and downstream faces inclined. Experiments on this type of weir were made by Bazin and the U.S. Deep Waterways Board. Bazin's experiments were all on weirs 2.64 ft high, the breadth of crest AB varying from 0.66 to 1.32 ft. Experiments on two

Table 5-3. Values of C in the Formula $Q = CLH^{3/2}$ for Broad-crested Weirs

Measured head in feet, H	Breadth of crest of weir in feet										
	0.50	0.75	1.00	1.50	2.00	2.50	3.00	4.00	5.00	10.00	15.00
0.2	2.80	2.75	2.69	2.62	2.54	2.48	2.44	2.38	2.34	2.49	2.68
0.4	2.92	2.80	2.72	2.64	2.61	2.60	2.58	2.54	2.50	2.56	2.70
0.6	3.08	2.89	2.75	2.64	2.61	2.60	2.68	2.69	2.70	2.70	2.70
0.8	3.30	3.04	2.85	2.68	2.60	2.60	2.67	2.68	2.68	2.69	2.64
1.0	3.32	3.14	2.98	2.75	2.66	2.64	2.65	2.67	2.68	2.68	2.63
1.2	3.32	3.20	3.08	2.86	2.70	2.65	2.64	2.67	2.66	2.69	2.64
1.4	3.32	3.26	3.20	2.92	2.77	2.68	2.64	2.65	2.65	2.67	2.64
1.6	3.32	3.29	3.28	3.07	2.89	2.75	2.68	2.66	2.65	2.64	2.63
1.8	3.32	3.32	3.31	3.07	2.88	2.74	2.68	2.66	2.65	2.64	2.63
2.0	3.32	3.31	3.30	3.03	2.85	2.76	2.72	2.68	2.65	2.64	2.63
2.5	3.32	3.32	3.31	3.28	3.07	2.89	2.81	2.72	2.67	2.64	2.63
3.0	3.32	3.32	3.32	3.32	3.20	3.05	2.92	2.73	2.66	2.64	2.63
3.5	3.32	3.32	3.32	3.32	3.32	3.19	2.97	2.76	2.68	2.64	2.63
4.0	3.32	3.32	3.32	3.32	3.32	3.32	3.07	2.79	2.70	2.64	2.63
4.5	3.32	3.32	3.32	3.32	3.32	3.32	3.32	2.88	2.74	2.64	2.63
5.0	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.07	2.79	2.64	2.63
5.5	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32	2.88	2.64	2.63

Table 5-4. Values of C in the Formula $Q = CLH^{3/2}$ for Models of Broad-crested Weirs with Rounded Upstream Corner

Name of experimenter	Radius of curve in feet	Breadth of weir in feet, B	Height of weir in feet, P	Head in feet, H									
				0.4	0.6	0.8	1.0	1.5	2.0	2.5	3.0	4.0	5.0
Basin..........	0.33	2.62	2.46	2.93	2.97	2.98	3.01	3.04					
Basin..........	0.33	6.56	2.46	2.70	2.82	2.87	2.89	2.92					
U. S. Deep Waterways...	0.33	2.62	4.57	....	2.77	2.80	2.83	2.92	3.00	3.08	3.17	3.34	3.50
U. S. Deep Waterways...	0.33	6.56	4.56	....	....	2.83	2.83	2.83	2.82	2.82	2.82	2.82	2.81

Table 5-5. Values of C in the Formula $Q = CLH^{3/2}$ for Broad-crested Weirs with Crests Inclined Slightly Downward

(a)

Crest	Energy head = H_e								
	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.4	1.5
Level....................	2.78	2.79	2.80	2.81	2.82	2.83	2.85	2.85	2.85
Slope = 0.004..........	2.95	2.94	2.93	2.92	2.91	2.90	2.88	2.87	2.87
Slope = 0.026..........	3.07	3.06	3.05	3.04	3.03	3.02	3.00	2.99	

(b)

Slope of crest	Length of weir in feet	Head in feet, H						
		0.1	0.2	0.3	0.4	0.5	0.6	0.7
12 to 1............	3.0	2.58	2.87	2.57	2.60	2.84	2.81	2.70
18 to 1............	3.0	2.91	2.92	2.53	2.60	2.80	2.74	2.62
18 to 1............	10.0	2.52	2.68	2.73	2.80	2.90	2.80	2.68

Table 5-6. Values of C in the Formula $Q = CLH^{3/2}$ for Weirs of Triangular Cross Section with Vertical Upstream Face and Sloping Downstream Face

Slope of downstream face	Height of weir in feet, P	Head in feet, H										
		0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.5
Hor. Vert.												
1 to 1	2.46	3.88	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85
2 to 1	2.46	3.48	3.48	3.49	3.49	3.50	3.50	3.50	3.50	3.50	3.51	3.51
2 to 1	1.64	3.56	3.47	3.47	3.51	3.54	3.57	3.58	3.58	3.58	3.59	3.57
3 to 1	1.64	....	2.90	3.11	3.22	3.26	3.33	3.37	3.40	3.40	3.41	3.41
5 to 1	2.46	....	3.06	3.06	3.05	3.05	3.07	3.09	3.12	3.13	3.13	3.13
10 to 1	2.46	....	2.82	2.83	2.84	2.86	2.89	2.90	2.91	2.91	2.92	2.93

Table 5-14. Errors in Weir Discharge Resulting from Errors in Measurement of Head

Discharge in second-feet Q	Error in head in feet	Weir 1 ft. long		Weir 2 ft. long		Weir 5 ft. long		Weir 10 ft. long		Right-angled V-notch wier	
		Head	Per cent. error in Q	Head	Per cent. error in Q	Head	Per cent. error in Q	Head	Per cent. error in Q	Head	Per cent. error in Q
0.05	0.001	0.06	2.6	0.04	4.0	0.02	8.0	0.01	12.0	0.20	1.2
	0.005		13.2		21.2		41.0		68.0		6.1
	0.010		26.6		43.6		85.0		144.0		12.2
0.10	0.001	0.09	1.6	0.06	2.6	0.03	5.0	0.02	8.0	0.27	0.9
	0.005		8.1		13.2		25.0		41.0		4.6
	0.010		16.4		26.6		51.5		85.0		9.1
0.50	0.001	0.27	0.5	0.17	0.9	0.09	1.6	0.06	2.6	0.52	0.5
	0.005		2.7		4.3		8.1		13.2		2.4
	0.010		5.5		8.7		16.4		26.6		4.8
	0.050		27.3		45.7		89.5				23.8
1.00	0.001	0.44	0.3	0.27	0.5	0.15	1.0	0.09	1.6	0.69	0.4
	0.005		1.7		2.7		5.0		8.1		1.8
	0.010		3.4		5.5		10.1		16.4		3.6
	0.050		17.0		27.3		53.6		89.5		18.0
2.50	0.001	0.82	0.2	0.51	0.3	0.27	0.5	0.17	0.9	1.00	0.3
	0.005		0.9		1.5		2.7		4.3		1.2
	0.010		1.8		3.0		5.5		8.7		2.5
	0.050		9.1		14.7		27.3		45.7		12.4
5.00	0.001	1.32	0.1	0.82	0.2	0.44	0.3	0.27	0.5	1.32	0.2
	0.005		0.6		0.9		1.7		2.7		0.9
	0.010		1.1		1.8		3.4		5.5		1.9
	0.050		5.6		9.1		17.0		27.3		9.2
10.00	0.001	2.11	0.1	1.32	0.1	0.71	0.2	0.44	0.3	1.75	0.1
	0.005		0.4		0.6		1.1		1.7		0.7
	0.010		0.7		1.1		2.1		3.4		1.5
	0.050		3.5		5.6		10.6		17.0		7.3
25.00	0.001	3.93	0.1	2.45	0.1	1.32	0.1	0.82	0.2	2.53	0.1
	0.005		0.2		0.3		0.6		0.9		0.5
	0.010		0.4		0.6		1.1		1.8		1.0
	0.050		1.8		3.0		5.6		9.1		5.0

HANDBOOK OF HYDRAULICS,
BRATER & KING
FIFTH EDITION 1963

Broad-Crested Weir Coefficients

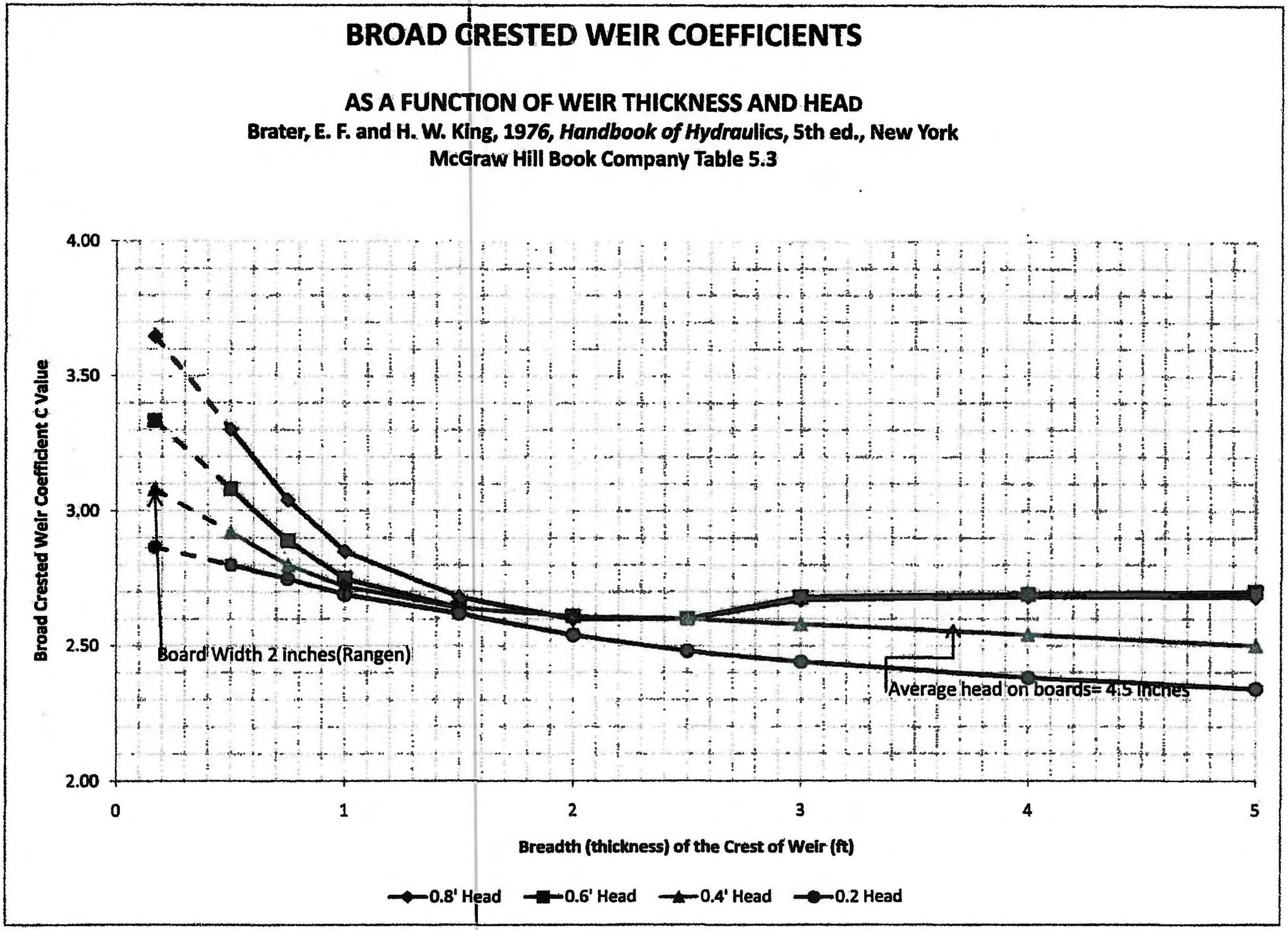
Broad-Crested Weir Coefficient C Values As A Function Of Weir Crest Breadth And Head

Measured Head, H[1] (mm)	Breadth Of The Crest Of Weir (m)										
	0.15	0.23	0.3	0.45	0.60	0.75	0.90	1.20	1.50	3.00	4.50
60	2.80	2.75	2.69	2.62	2.54	2.48	2.44	2.38	2.34	2.49	2.68
120	2.92	2.80	2.72	2.64	2.61	2.60	2.58	2.54	2.50	2.56	2.70
180	3.08	2.89	2.75	2.64	2.61	2.60	2.68	2.69	2.70	2.70	2.70
240	3.30	3.04	2.85	2.68	2.60	2.60	2.67	2.68	2.68	2.69	2.64
300	3.32	3.14	2.98	2.75	2.66	2.64	2.65	2.67	2.68	2.68	2.63
360	3.32	3.20	3.08	2.86	2.70	2.65	2.64	2.67	2.66	2.69	2.64
420	3.32	3.26	3.20	2.92	2.77	2.68	2.64	2.65	2.65	2.67	2.64
480	3.32	3.29	3.28	3.07	2.89	2.75	2.68	2.66	2.65	2.64	2.63
240	3.32	3.32	3.31	3.07	2.88	2.74	2.68	2.66	2.65	2.64	2.63
600	3.32	3.31	3.30	3.03	2.85	2.76	2.27	2.68	2.65	2.64	2.63
750	3.32	3.32	3.31	3.28	3.07	2.89	2.81	2.72	2.67	2.64	2.63
900	3.32	3.32	3.32	3.32	3.20	3.05	2.92	2.73	2.66	2.64	2.63
1,050	3.32	3.32	3.32	3.32	3.32	3.19	2.97	2.76	2.68	2.64	2.63
1,200	3.32	3.32	3.32	3.32	3.32	3.32	3.07	2.79	2.70	2.64	2.63
1,350	3.32	3.32	3.32	3.32	3.32	3.32	3.32	2.88	2.74	2.64	2.63
1,500	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.07	2.79	2.64	2.63
1,650	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32	2.88	2.64	2.63

Measured Head, H[1] (ft)	Breadth Of The Crest Of Weir (ft)										
	0.50	0.75	1.00	1.50	2.00	2.50	3.00	4.00	5.00	10.00	15.00
0.2	2.80	2.75	2.69	2.62	2.54	2.48	2.44	2.38	2.34	2.49	2.68
0.4	2.92	2.80	2.72	2.64	2.61	2.60	2.58	2.54	2.50	2.56	2.70
0.6	3.08	2.89	2.75	2.64	2.61	2.60	2.68	2.69	2.70	2.70	2.70
0.8	3.30	3.04	2.85	2.68	2.60	2.60	2.67	2.68	2.68	2.69	2.64
1.0	3.32	3.14	2.98	2.75	2.66	2.64	2.65	2.67	2.68	2.68	2.63
1.2	3.32	3.20	3.08	2.86	2.70	2.65	2.64	2.67	2.66	2.69	2.64
1.4	3.32	3.26	3.20	2.92	2.77	2.68	2.64	2.65	2.65	2.67	2.64
1.6	3.32	3.29	3.28	3.07	2.89	2.75	2.68	2.66	2.65	2.64	2.63
1.8	3.32	3.32	3.31	3.07	2.88	2.74	2.68	2.66	2.65	2.64	2.63
2.0	3.32	3.31	3.30	3.03	2.85	2.76	2.27	2.68	2.65	2.64	2.63
2.5	3.32	3.32	3.31	3.28	3.07	2.89	2.81	2.72	2.67	2.64	2.63
3.0	3.32	3.32	3.32	3.32	3.20	3.05	2.92	2.73	2.66	2.64	2.63
3.5	3.32	3.32	3.32	3.32	3.32	3.19	2.97	2.76	2.68	2.64	2.63
4.0	3.32	3.32	3.32	3.32	3.32	3.32	3.07	2.79	2.70	2.64	2.63
4.5	3.32	3.32	3.32	3.32	3.32	3.32	3.32	2.88	2.74	2.64	2.63
5.0	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.07	2.79	2.64	2.63
5.5	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32	2.88	2.64	2.63

[1]Measured at least 2.5H upstream of the weir.

Reference: Brater and King (1976).


BROAD CRESTED WEIR COEFFICIENTS
AS A FUNCTION OF WEIR THICKNESS AND HEAD
Brater, E. F. and H. W. King, 1976, Handbook of Hydraulics, 5th ed., New York
McGraw Hill Book Company Table 5.3
Broad Crested Weir Coefficient C Value
4.00
3.50
3.00
2.50
2.00
0
1
2
3
4
5
Breadth (thickness) of the Crest of Weir (ft)
Board Width 2 inches(Rangen)
Average head on boards= 4.5 inches
0.8' Head
0.6' Head
0.4' Head
0.2 Head