Hydrological Modelling

with

Green Kenue™ and WATFLOOD™

MRBB Workshop – Edmonton, June 7, 2016
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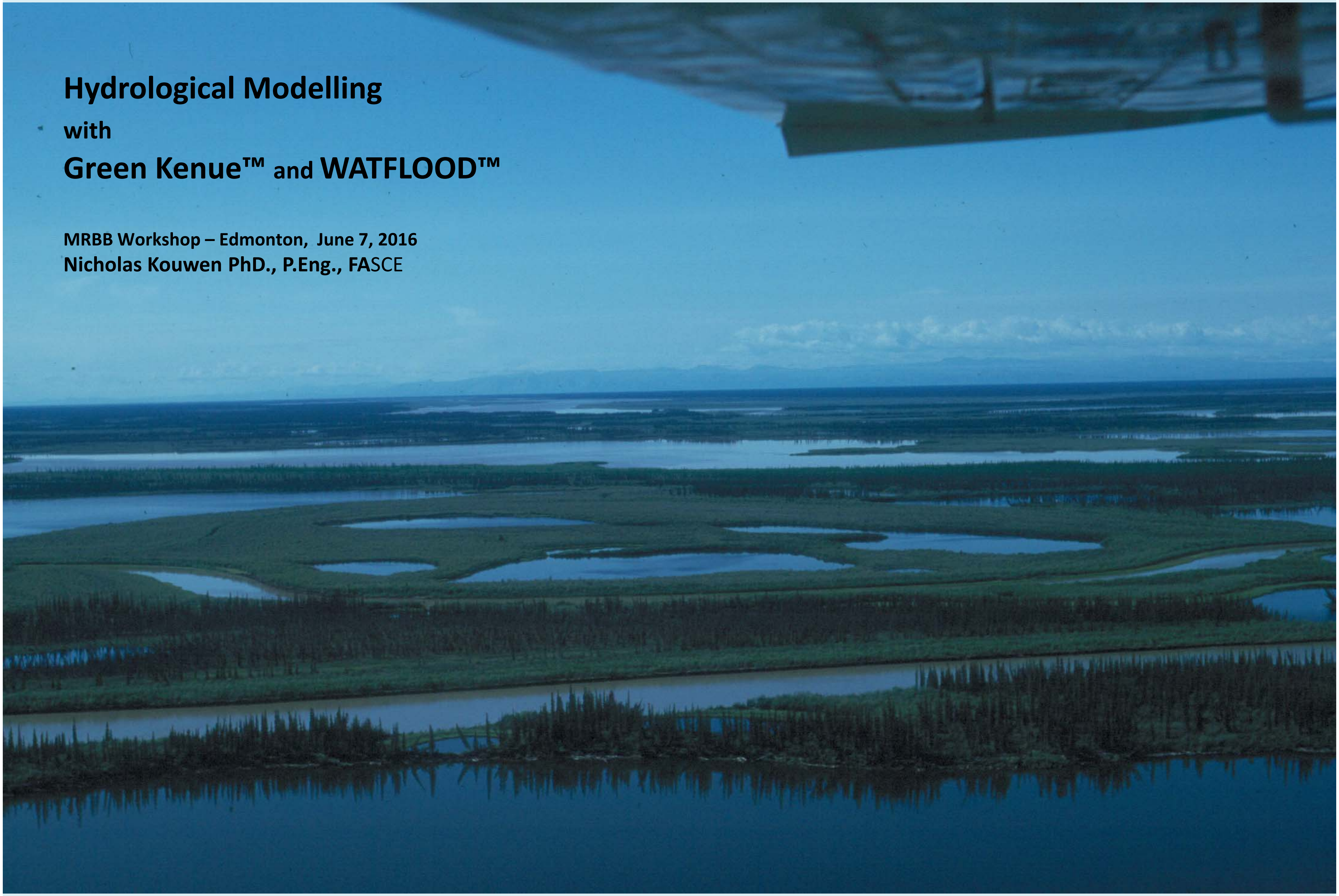


Mackenzie River delta North of Inuvik

Bennet Dam – Williston Lake

Peace River west of Fort St. John – Halfway River Junction

Halfway River junction

Peel River -- Wernecke Mountains (?)

Nahoni Range -- Peel River -- Wernecke Mountains

Dempster Highway – through Richardson Mountains??

Peel River crossing near Fort McPherson

Mackenzie River ferry at Arctic Red River

Modelling objectives for WATFLOOD™

- **Flood forecasting and flood studies**
- Continuous modelling – climate change impacts
- Ability to model very large as well as small domains
- Ability to <u>optimally</u> use gridded data sources e.g.. Land cover, DEM's, NWP model output, Radar data
- Universally applicable parameter set (maybe)
- Quick turn around (for a distributed model)
- <u>**Ability to model a wide variety of landscapes**</u>

On choosing a model:

- You would choose WATFLOOD if its particular capabilities are advantageous – e.g.:
  - Highly spatially variable radar of numerical weather model input
  - Climate change scenarios
  - Modelling ungauged basins
  - Modelling very large regions
  - Calibration/validation with point state variable data e.g. SWE
  - Isotope model (only watershed O^{18} & 2H model in existence!!)
  - Extensive wetland/bank storage
  - Intricate hydraulics (lakes & reservoirs)
  - **Pre & Post Processor: GreenKenue**

Distributed vs. Lumped models

With WATFLOOD the measurable quantities for each cell are:

- Bankfull cross sectional area
- Channel slope
- Overland slope
- Cell elevations (min,mean,max)
- Channel classification
- Channel length (in grid)
- Cell connectivity (channel or lake routing)
- **% area of each hydrologically similar land cover (GRU)**
- Water & wetland areas

Distributed vs. Lumped models (cont'd)

- **For lumped models all these measurable quantities are combined into watershed parameters which vary with the watershed's makeup of the measurable quantities and are optimized.**
- **For distributed models, each of these measurable characteristics are explicitly incorporated – thus parameters are not "watershed based"**
- **PRO**: Distributed models should be better at predicting flow from ungauged watersheds
- **CON**: There is a cost: Distributed models are more difficult to calibrate and have longer execution time.

WATFLOOD Features

- Watflood is a DISTRIBUTED model (Gridded & GRU)
- Grouped response units (GRU's): will lead to universal parameter set
- Gridded model:
  - **optimal** use of remotely sensed data
  - **optimal** use of numerical weather data
  - **optimal** use of 1,2 and 3D display facilities (e.g. GreenKenue™)
- Tracer & Isotope model
- In WATFLOOD we ignore connectivity at the small scale (within cell)

History

- **1972 MNR Ontario**. Original idea was to have a gridded model to coupled with weather radar – no one else interested, EC data not free
- Gridded model turned out to be easily and optimally interfaced with remotely sensed land cover data - GRU's developed in 1985
- Early 1988's Env. Can. became interested – set up radar interface 1992
- 1993-1998 BC Hydro dam safety study with Numerical Weather Model MC2/WATFLOOD
- 1999 **M**esoscale **A**lpine **P**roject (**MAP**): MC2/WATFLOOD real-time flow forecast experiment. WATFLOOD used to validate MC2 precip forecast.
- 2004 - 2008 development continued for ensemble forecasting
  - WATFLOOD modified to fully integrate with Green Kenue (ENSIM) (common file formats)
  - Great Lakes model
  - Mackenzie river forecast model – coupled to River1D
- 2008 Manitoba Hydro adopts WATFLOOD for climate change study & planning
- 2012 -2014 **MH, OMNR, LWCB, OPG** implementing flow forecasting with WATFLOOD & Numerical Weather forecasts

Previous Uses:

- Flow forecasting (1972) – original intent, only now being implemented
- Climate change impacts
- Land use change impacts
- Numerical weather model validation (i.e. watershed = precip gauge)
- Dam safety

- GRU's
  - need
  - limitations

- No two watersheds are alike!!!!!

- It is impossible to transfer any but the simplest parameters form one watershed to another (e.g. area, slope, shape, vegetation, channel character all different)

- It just seems way more reasonable to define parameters based on land cover & topography – i.e things you can measure

- **It is our contention that the use of land cover based parameters makes the model much more robust for modelling ungauged watersheds (see better validation errors in the ASCE paper)**

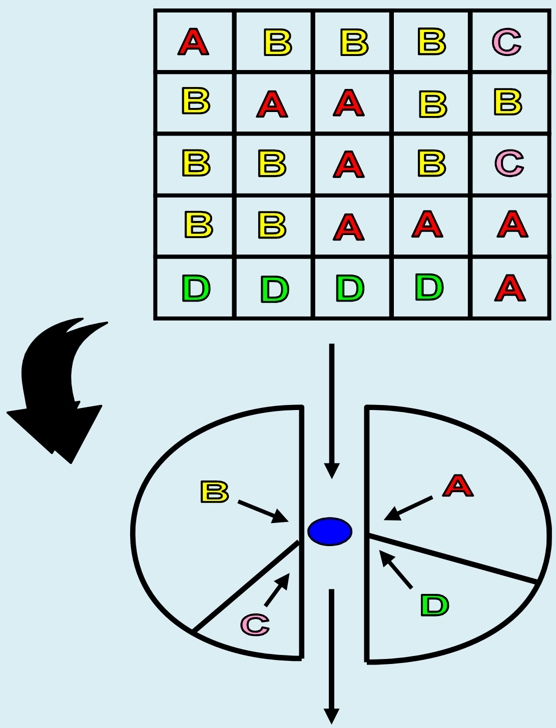
Model setup & calibration

- **GreenKenu**e™ (GK) for model setup
  - Few decisions
    - (main one: cell size)
    - Number of land covers to model seperately
    - Coding lakes
    - Coupled wetland proportion
- Pre-processors for HYDAT, WISKI, etc. data files → GK format files for WATFLOOD

Hydrology

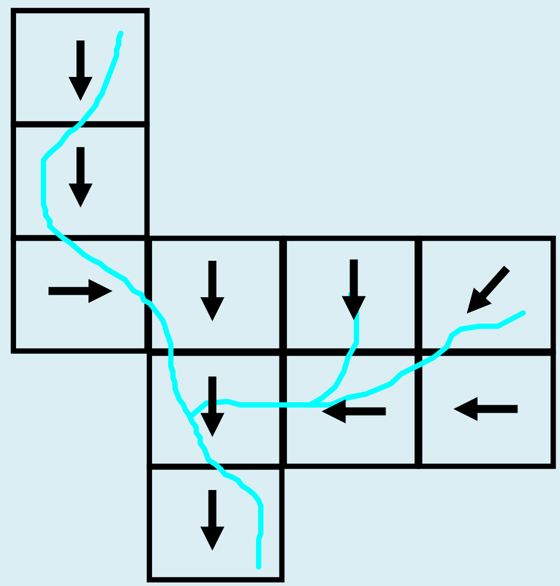
Group Response Unit

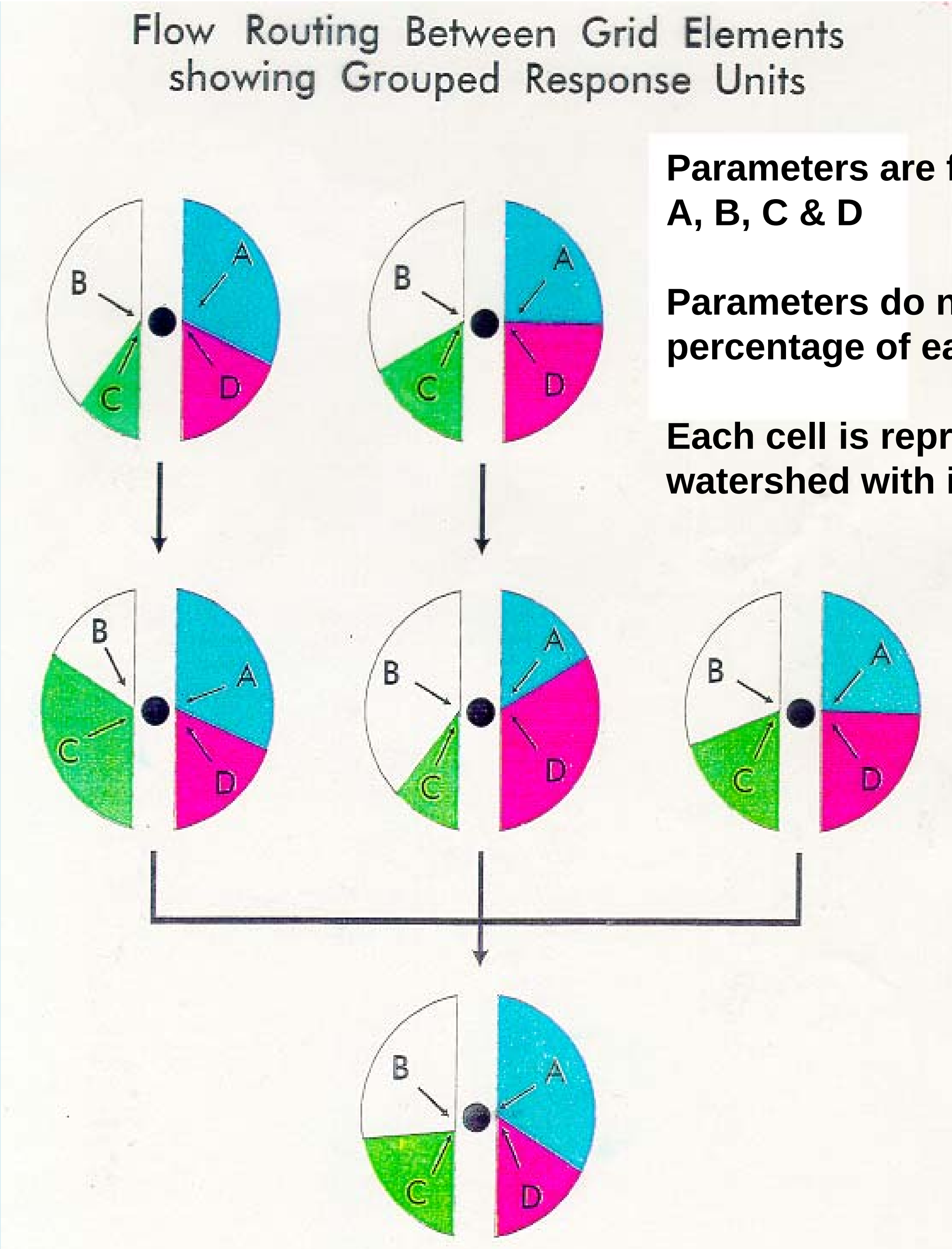
- to deal with basin heterogeneity



Hydraulics

Physically Based Streamflow Routing





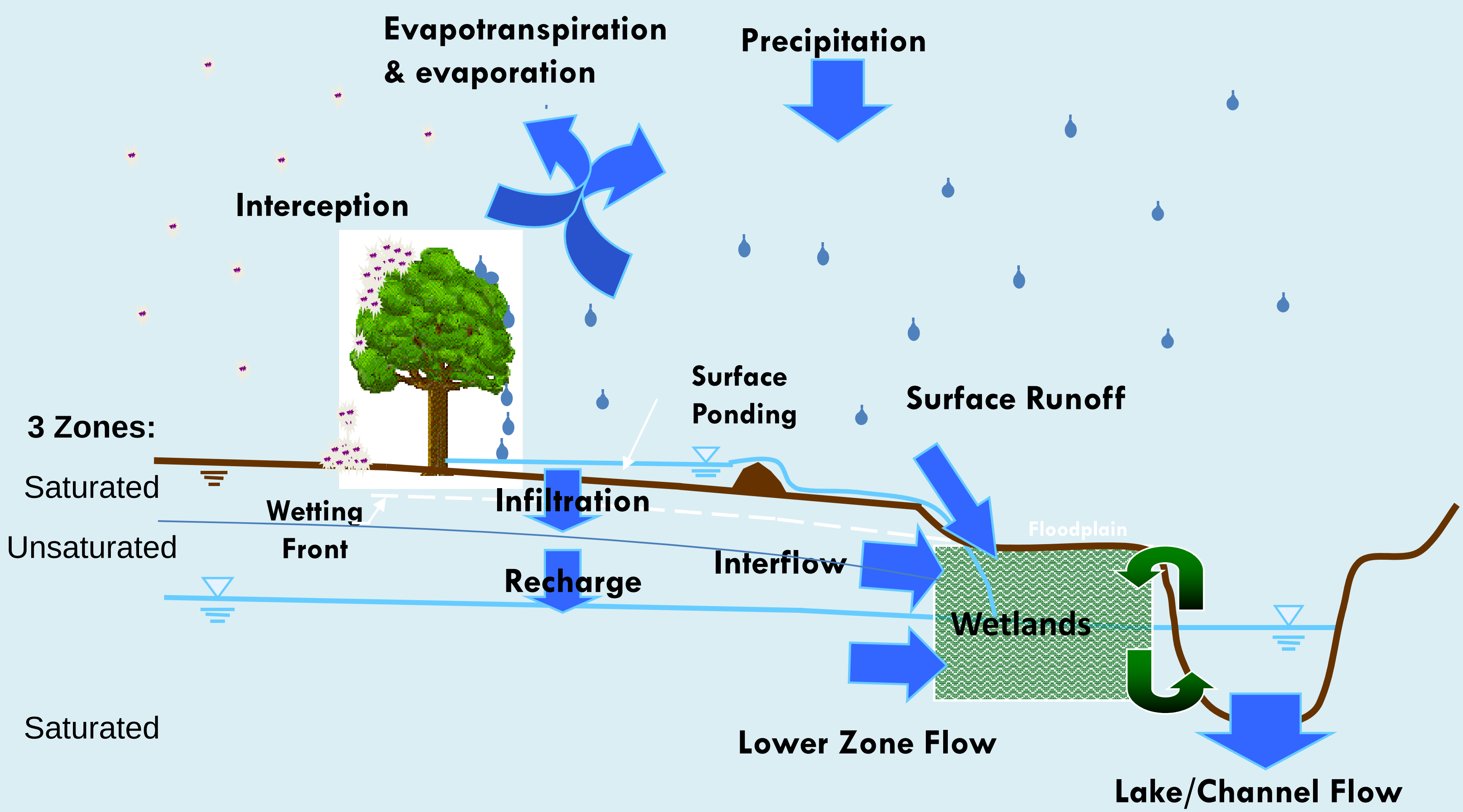
Parameters are for land cover classes A, B, C & D

Parameters do not change with percentage of each land cover

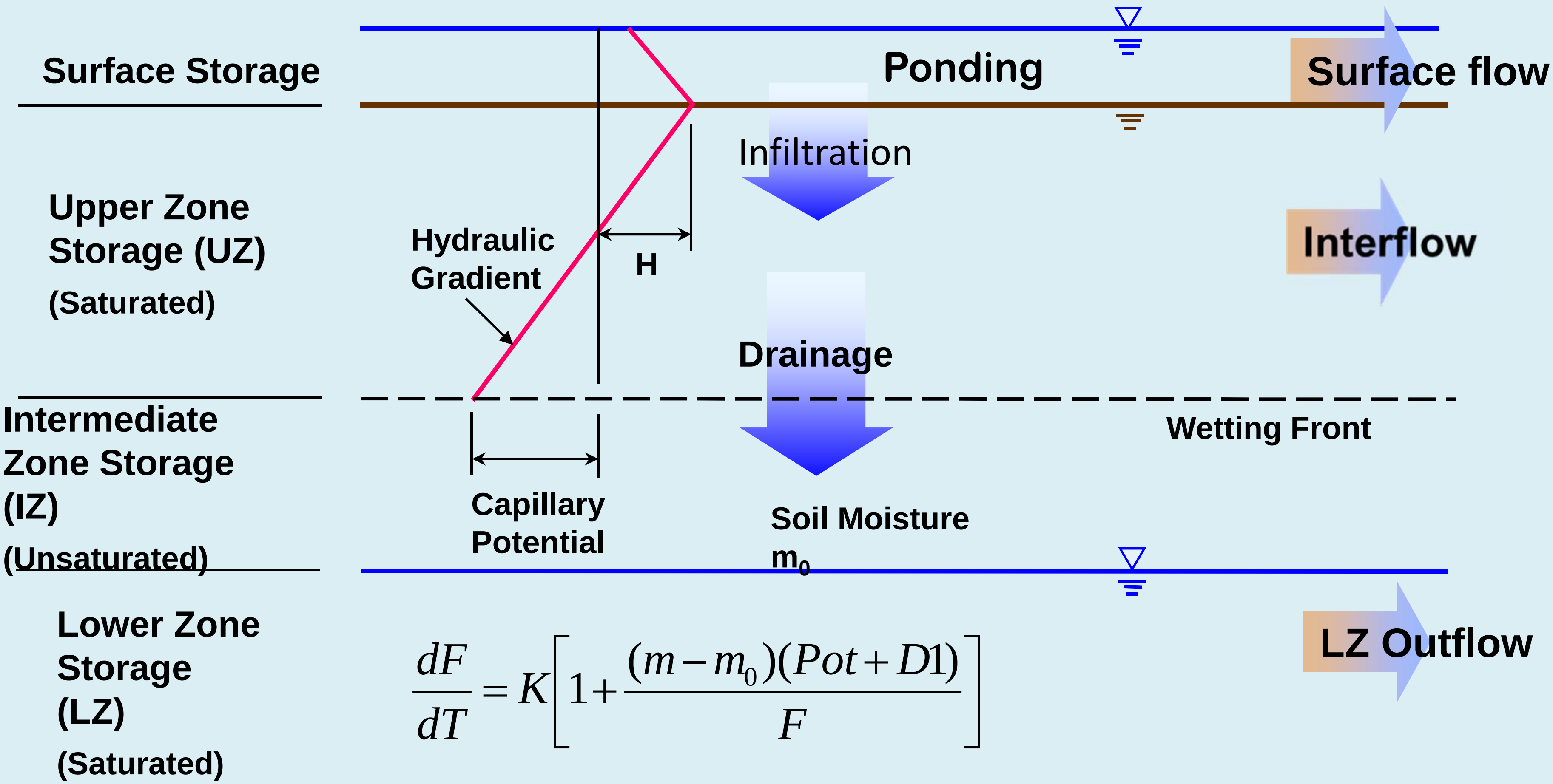
Each cell is represented by a watershed with its own cover allocation.

% cover can change over time !!!

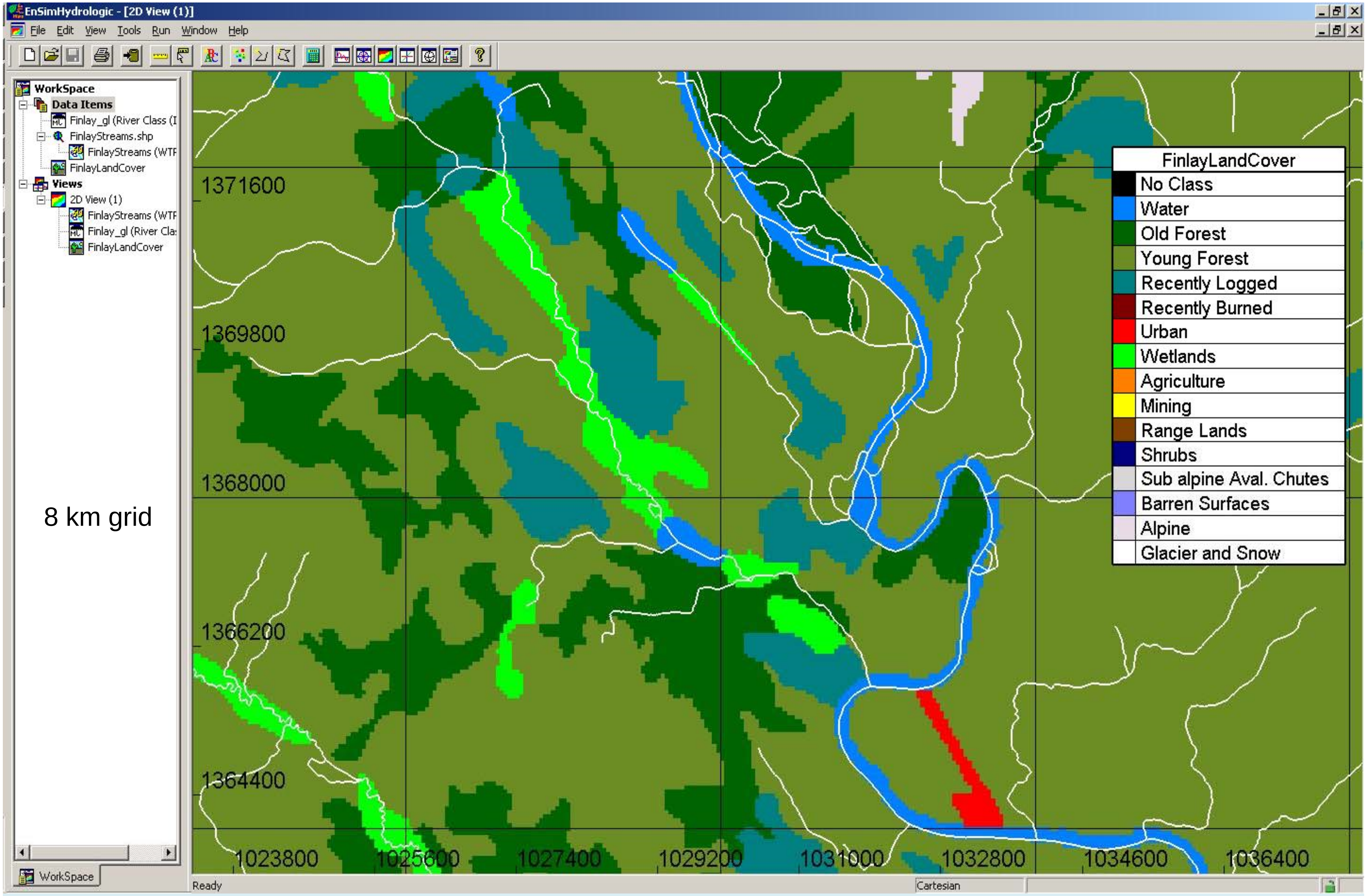
WATFLOOD™
Hydrological Model



Schematic of the Infiltration Process



$$\frac{dF}{dT} = K\left[1 + \frac{(m - m_0)(Pot + D1)}{F}\right]$$



GRU’s & Coupled wetlands - e.g. Finlay River, BC

Each cell has these attributes:

•Cells are numbered from upstream to the outlet (highest to lowest elevation)

•***Evapotranspiration, Snow Melt, Runoff and Recharge is computed for each land cover class in each cell – GRU method***

•Runoff is routed to the stream-coupled wetland and then to the stream channel or lake in each grid

•Channel & Lake flows are routed from cell to cell in downstream direction:

- •Channel routing: with KW & Manning's n
- •**Coded** Lake routing: with releases or storage-discharge function
- •**Un-coded** lakes: wide channels to preserve water area in each cell and to dampen flow raised Manning's n prop'l to water area

Modularity

- separate programming units for:
  - Setup
    - Watershed representation: GreenKenue™
    - Event generation
    - Point data to distributed data conversion for meteorological inputs (distance weighting with radius of influence, damping coefficient & lapse rates OR user supplied)
  - Hydrology/Routing: WATFLOOD™
  - Parameter fitting: DDS
  - Post processing: GreenKenue™, Grapher™, Surfer™, Excel™, etc.
  - Statistical analysis of output: Excel™, other stats software

Interfacing with other models (flavours)

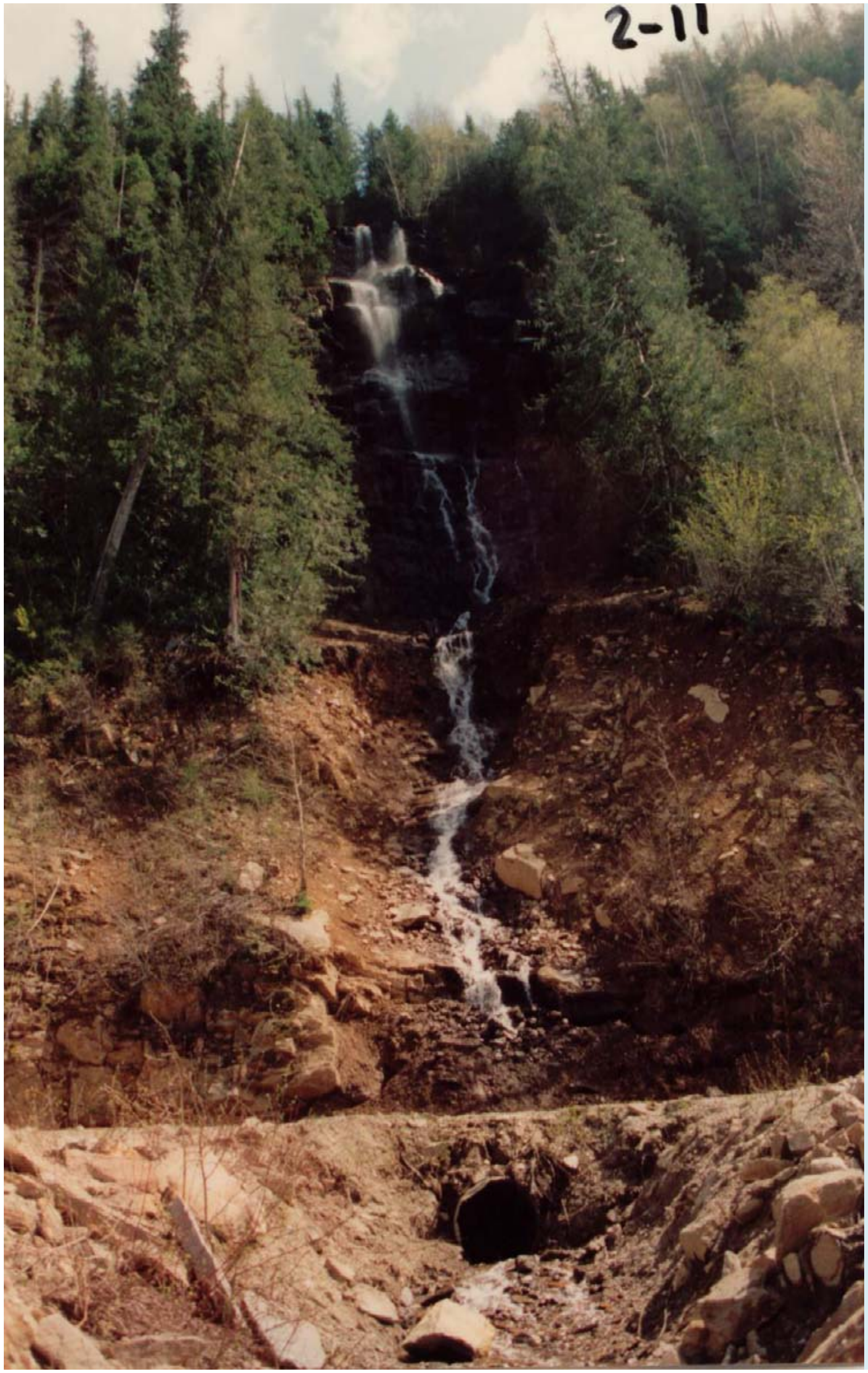
- Gridded model allows 1 to 1 matching of runoff units to meteorological driving data from NWM (eg. EC's GEM)
- Gridded surface model allows 1 to 1 matching of recharge to groundwater model such as **MODFLOW**
- **Computed river inflows can be accumulated on a reach by reach basis for input to an <u>internal Lake routing module</u> or be written to a file in a format compatible with routing models such as DWOPER, Flow1D, River1D, TELEMAC or some other application (e.g. ice jam model).**
- Grid outflow computed with any model can be routed with WATROUTE (a subset of WATFLOOD Code)

Scaling/Domain Size

- WATFLOOD has been used with cell sizes from 1 to 25 km (scale) and for watershed areas from 15 to 1,700,000 km^2 (domain)

- WATFLOOD is not sensitive to cell size as long as there are a sufficient number of cells to maintain the integrity of the drainage system and preserve the variability in the meteorological data

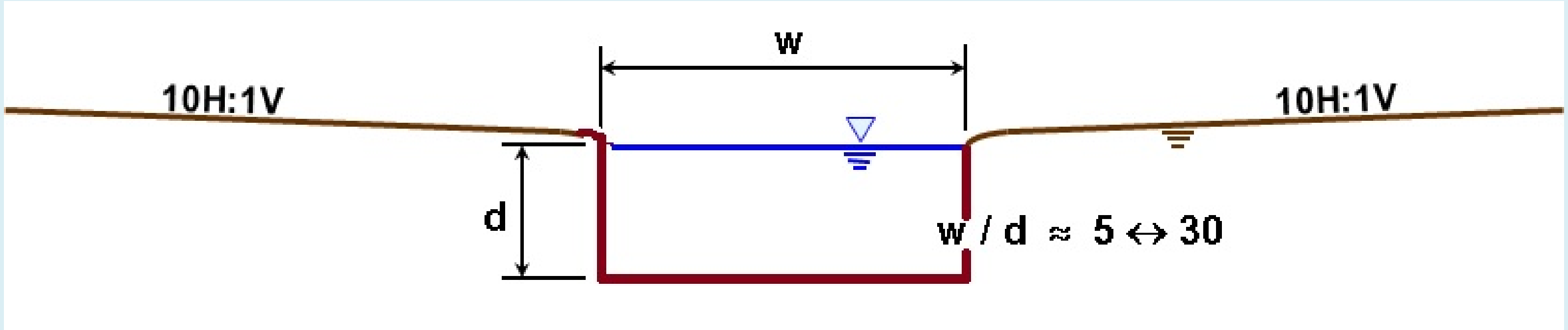
- Regional model: models multiple watersheds (**WATFLOOD cannot be properly calibrated with one or two flow stations**)



Routing features

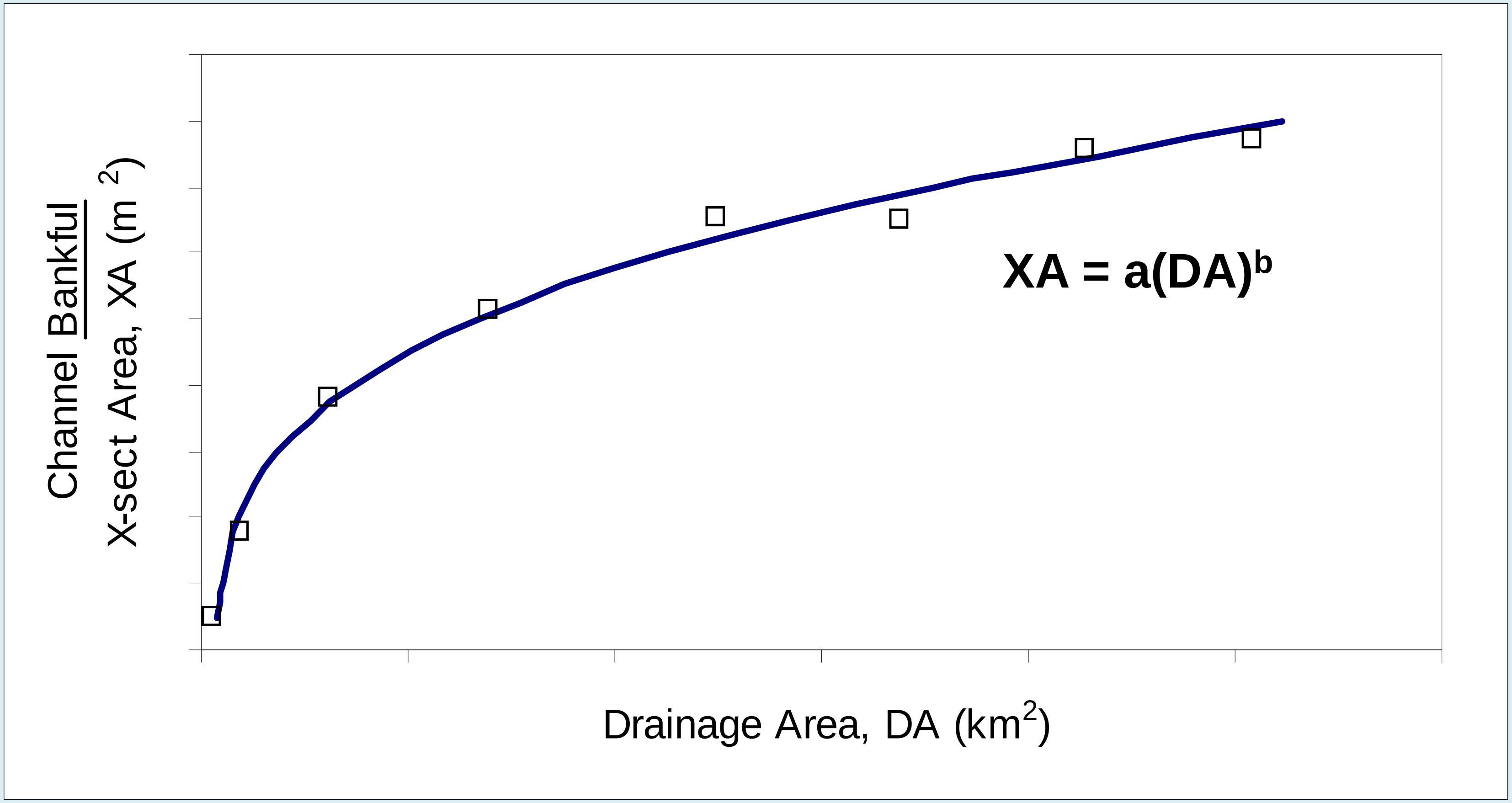
- •Storage routing (center difference KW solution with variable time steps to satisfy Courant criteria everywhere)
- •Coupled stream-wetland routing model
- •Lake routing, reservoir operating rules & diversions
- •Overbank flow (with different resistance coefficients)
- •River, Lake and groundwater initialization based on recession curve of observed hydrographs.

Assumed Channel Section



- Fieldwork is still required to confirm assumed section
- Channel & overbank roughness separately set

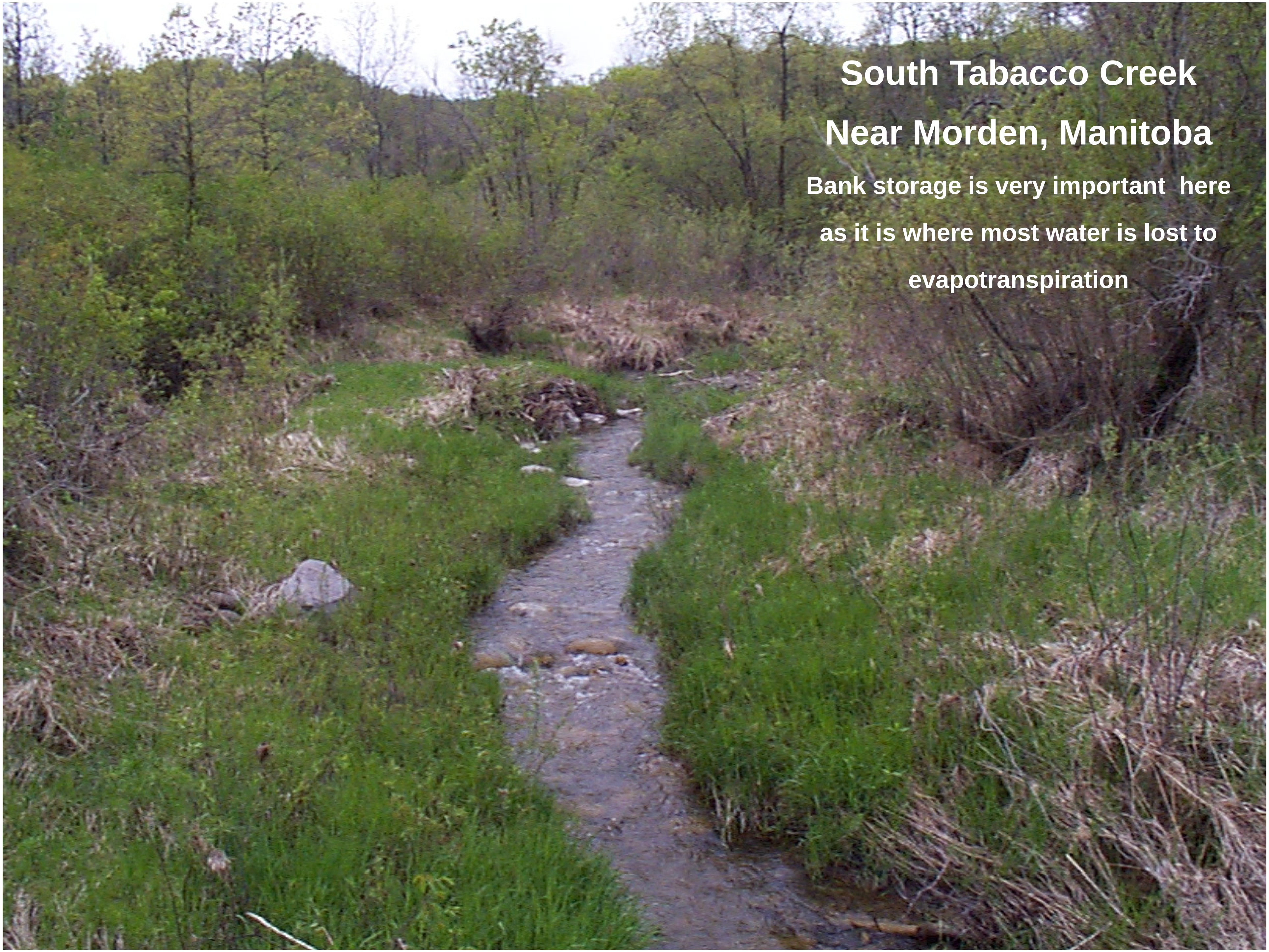
Channel Cross-Section - Drainage Area Relationship



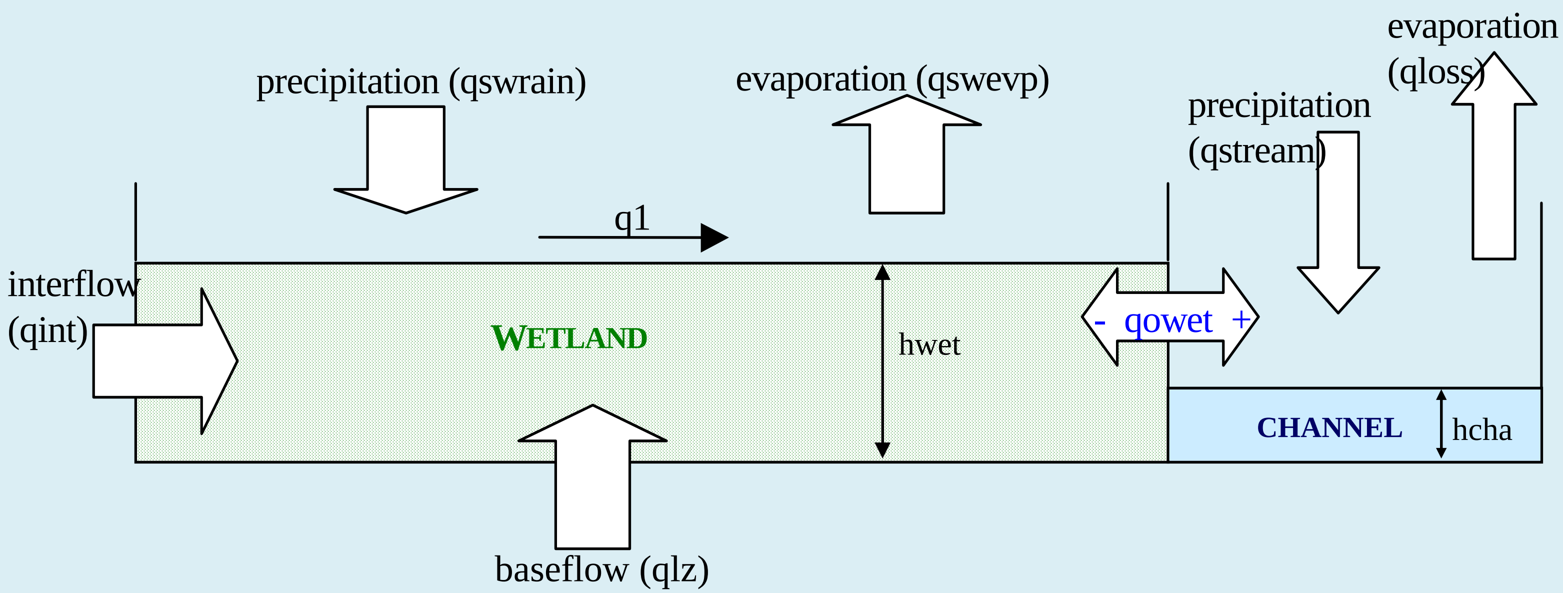
Wetland/Bank Storage Model

coded by Trish Stadnyk
based on PhD by Bob McKillop

BOREAS NSA Fen Site:


South Tabacco Creek
Near Morden, Manitoba
Bank storage is very important here
as it is where most water is lost to
evapotranspiration

Wetland model schematic

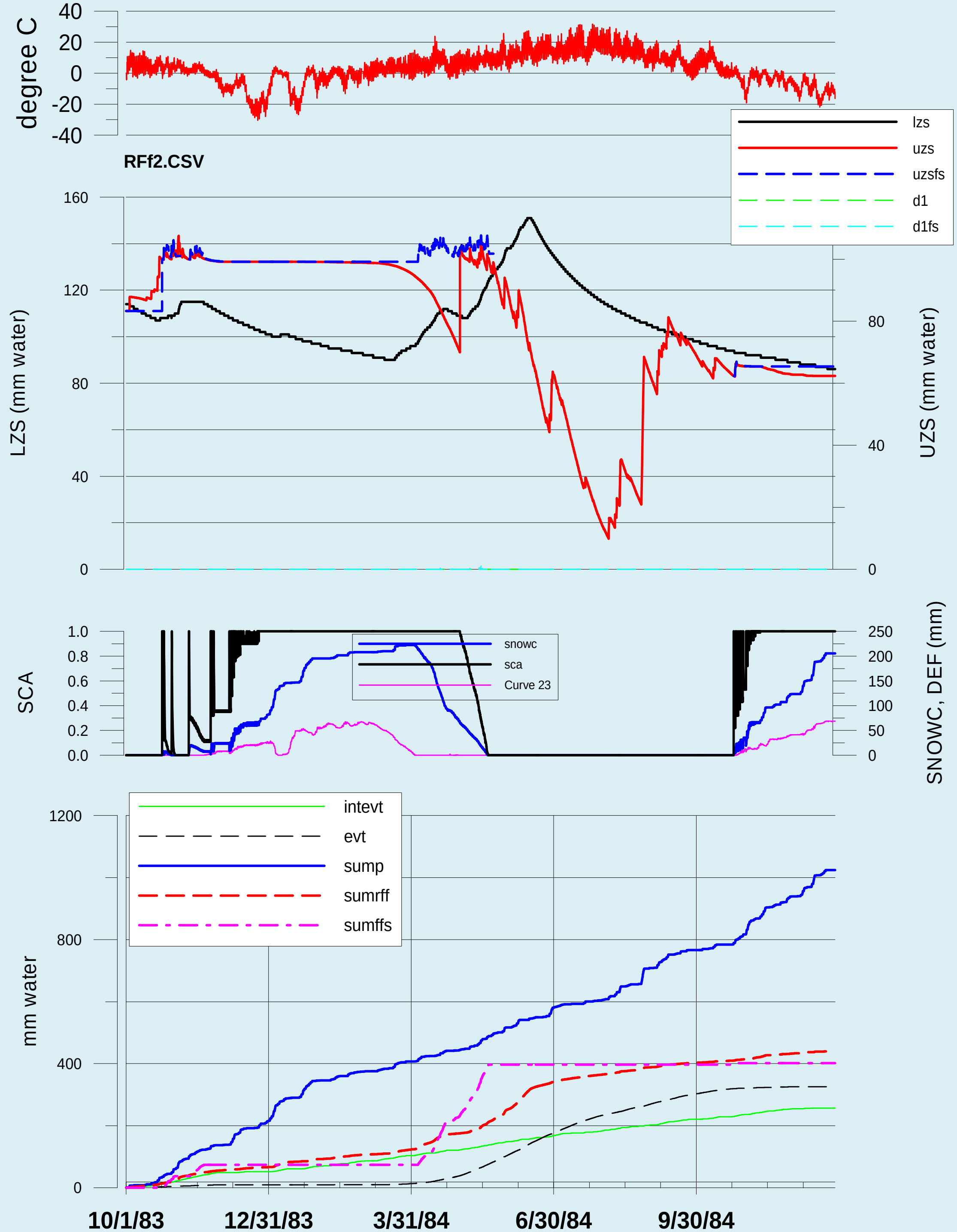


Does the model work?

i.e. does it model nature?

Physical hydrological reasonableness:

- Where possible, time series of state variables are compared to observed data (e.g. SWE, lake levels, GW levels, soil moisture, O.
- All model components have been individually verified

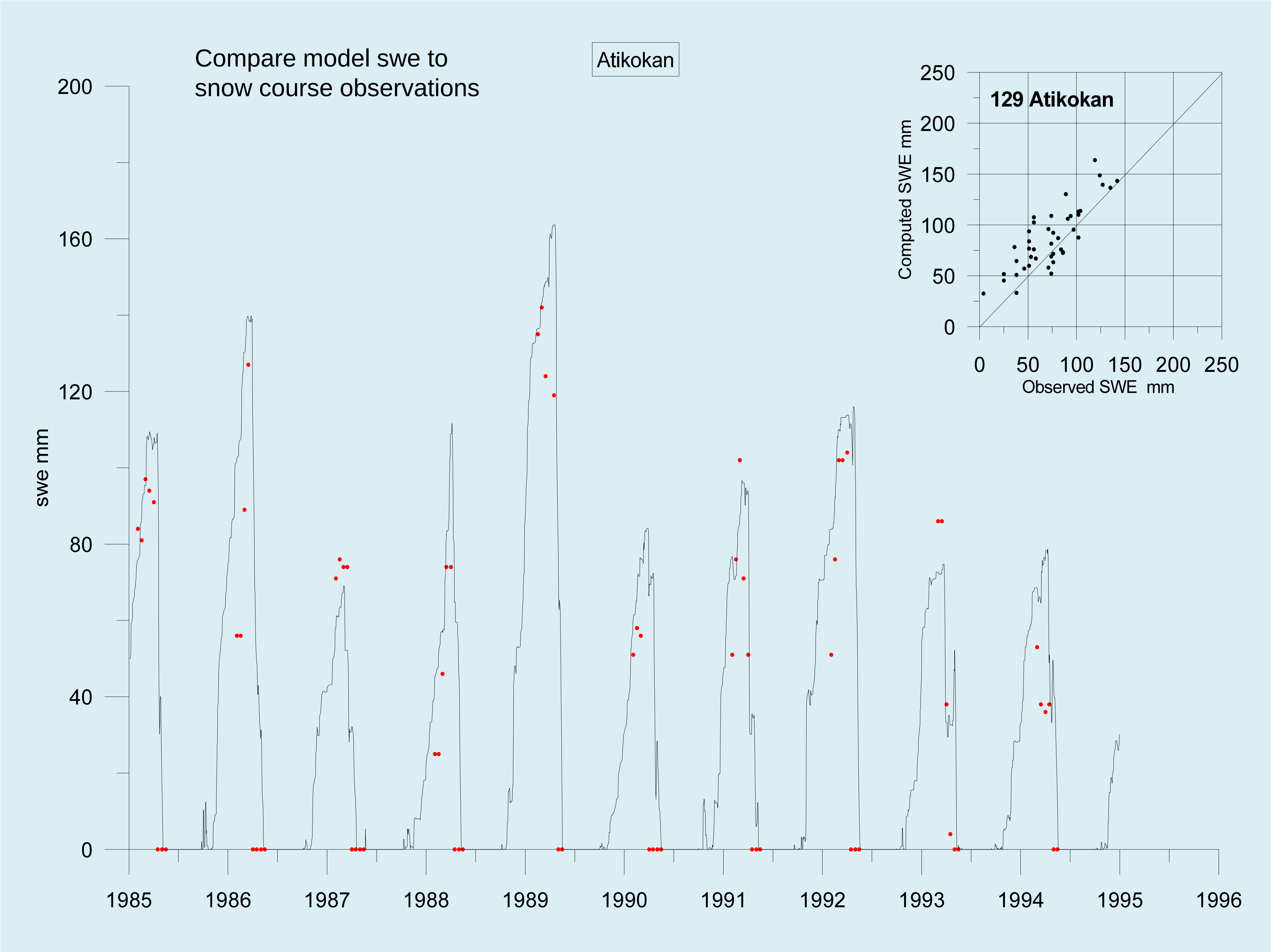


Plots are used to check if general principles are ok.

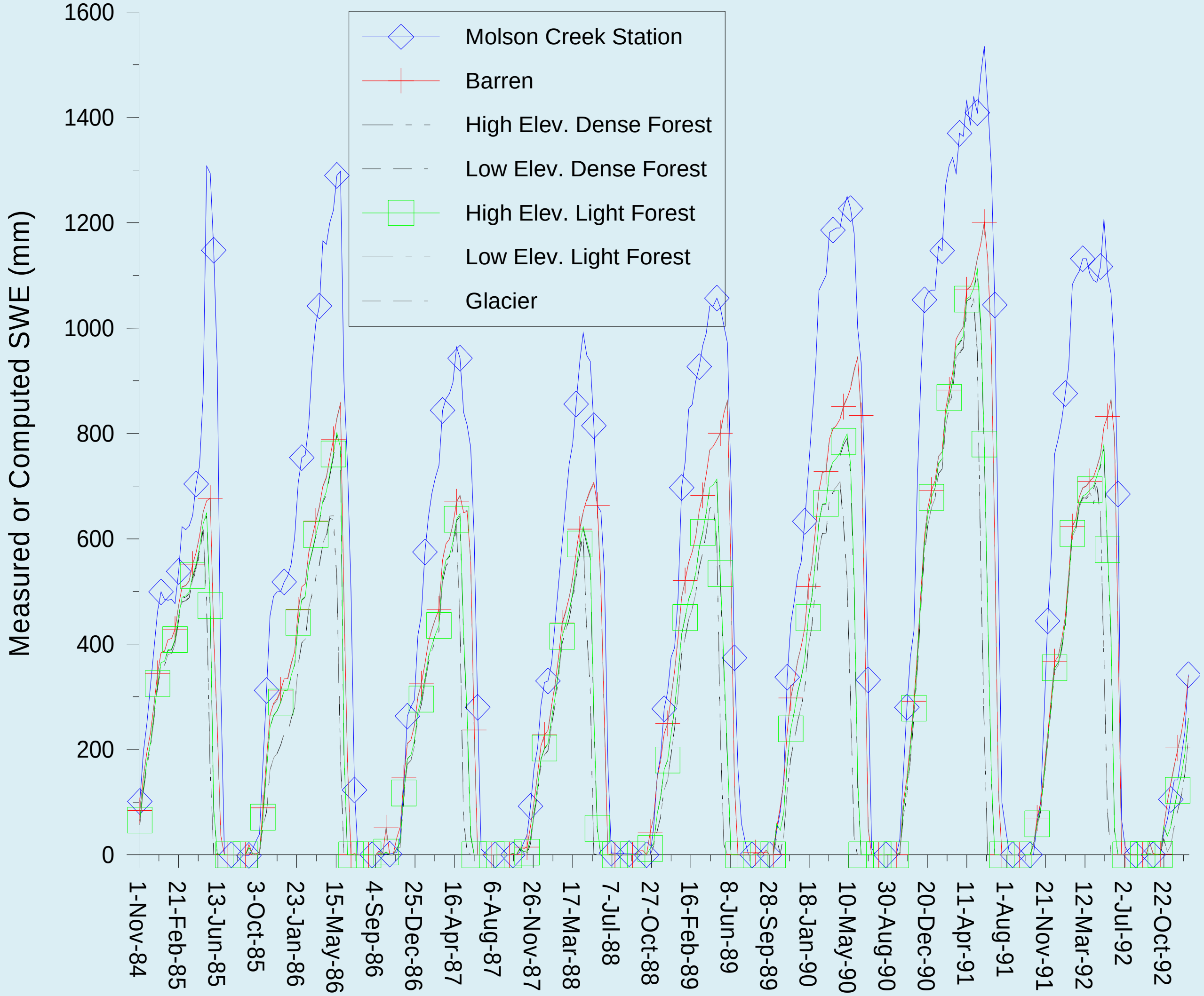
Plot of UZS and LZS

Plots of snow covered area, snow water equivalent and snow pack heat deficit.

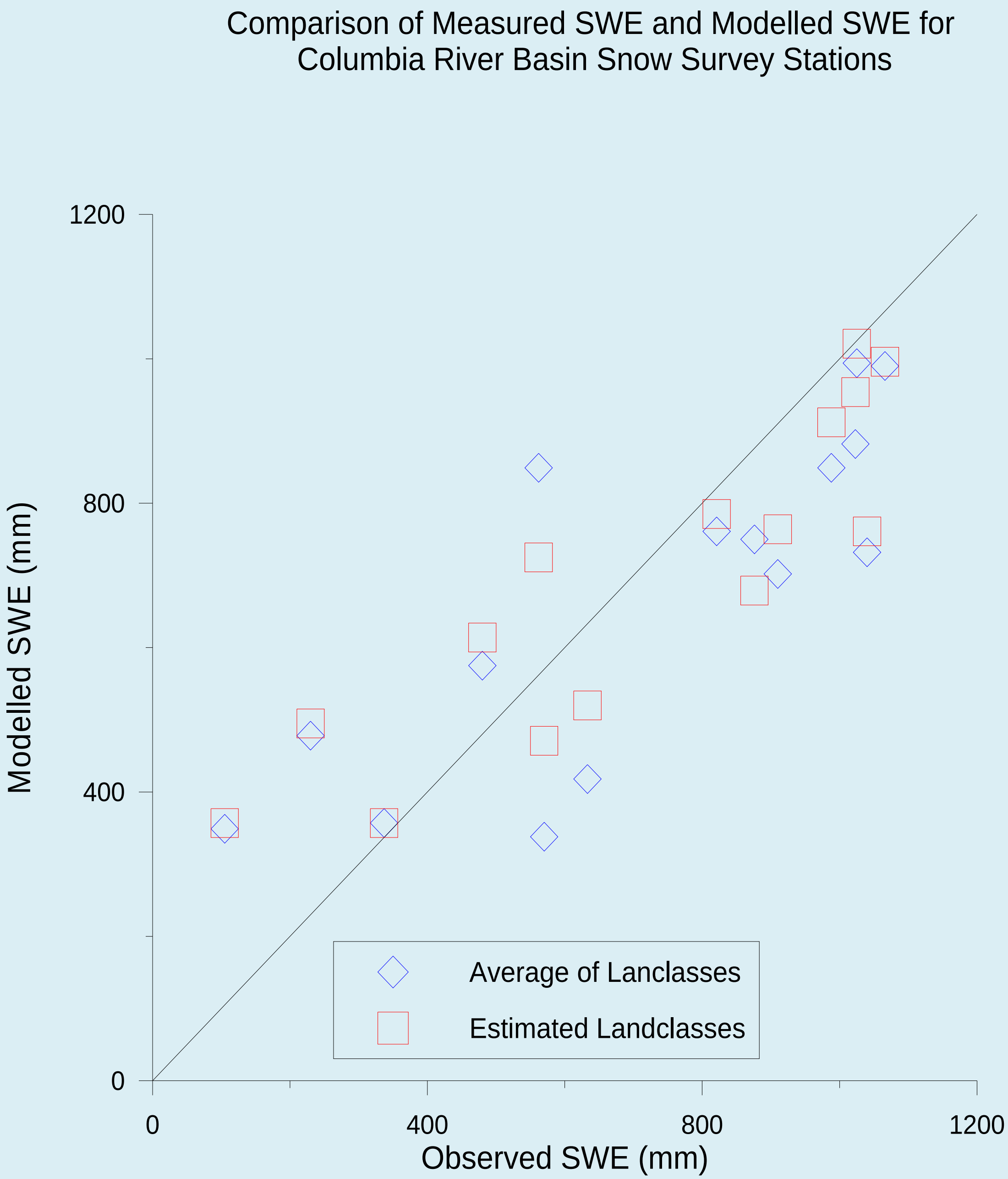
Plots of cumulative precipitation, evaporation and runoff.



Compare model swe to
snow course observations
Atikokan
swe mm
200
160
120
80
40
0
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
129 Atikokan
Computed SWE mm
Observed SWE mm
250
200
150
100
50
0
0
50
100
150
200
250

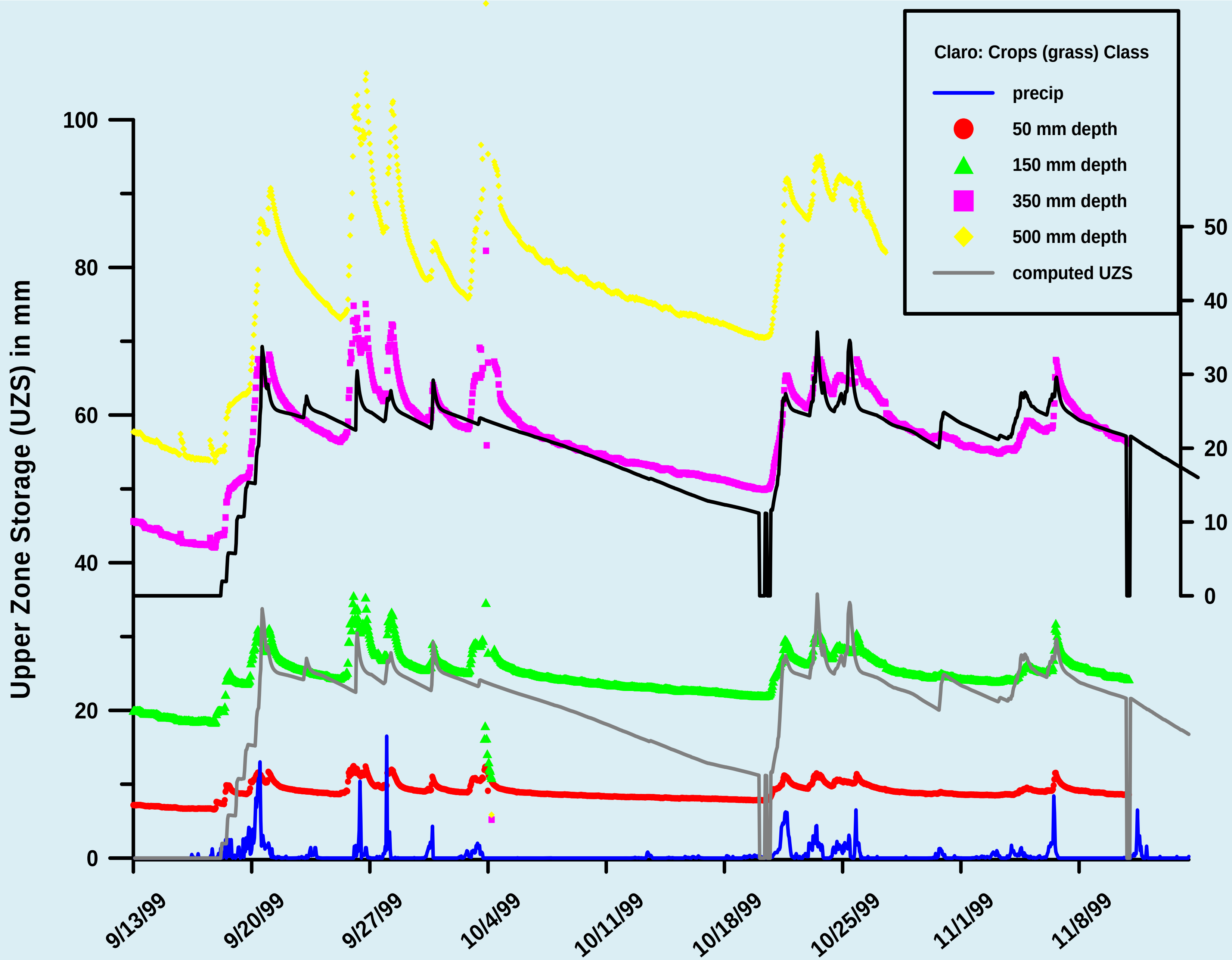


Comparison of snow pillow data and WATFLOOD/SPL SWE estimates by Janet Wong BCH

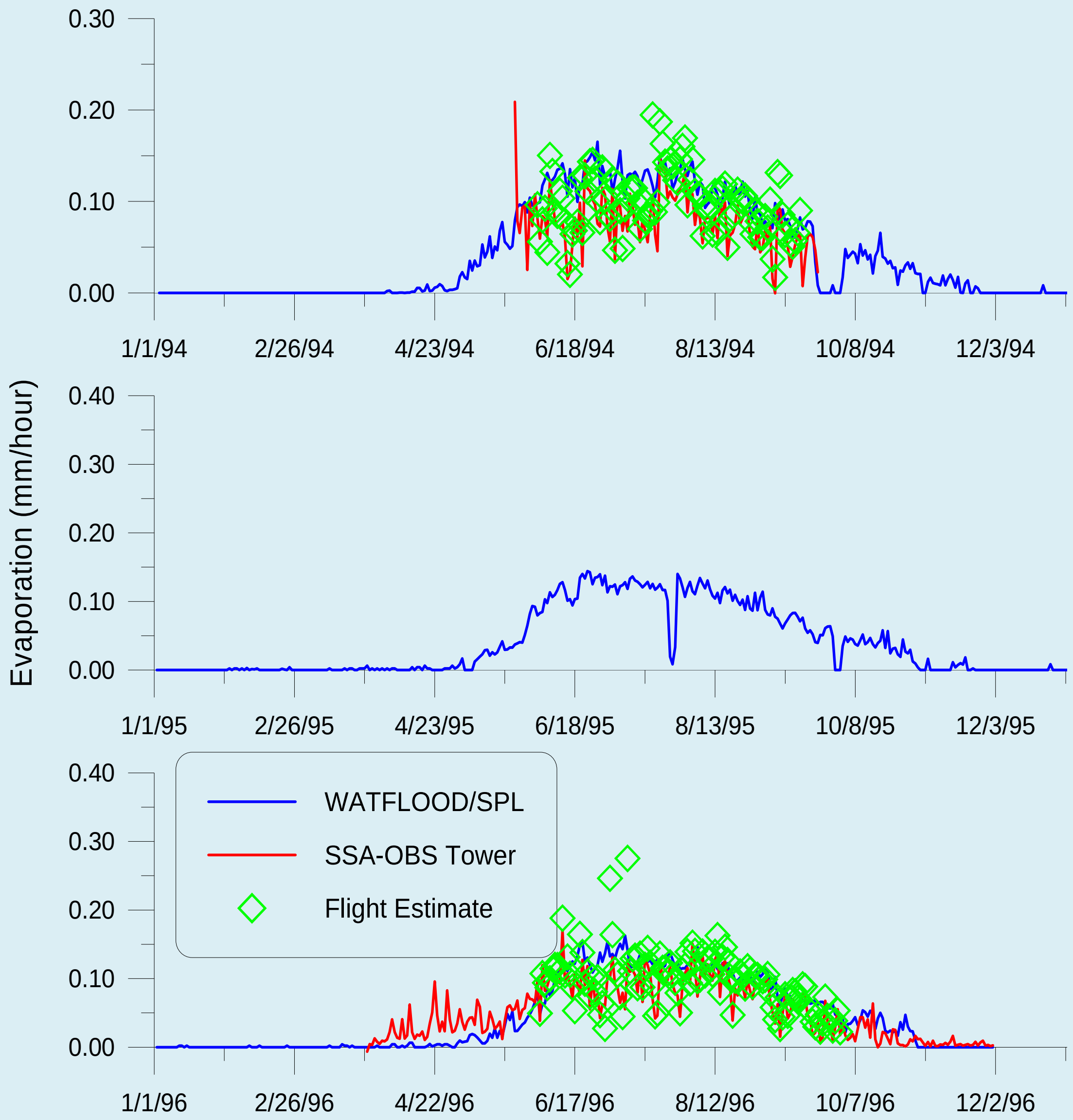


Comparison of observed SWE to modelled SWE for for the Columbia River basin.

Janet Wong BCH

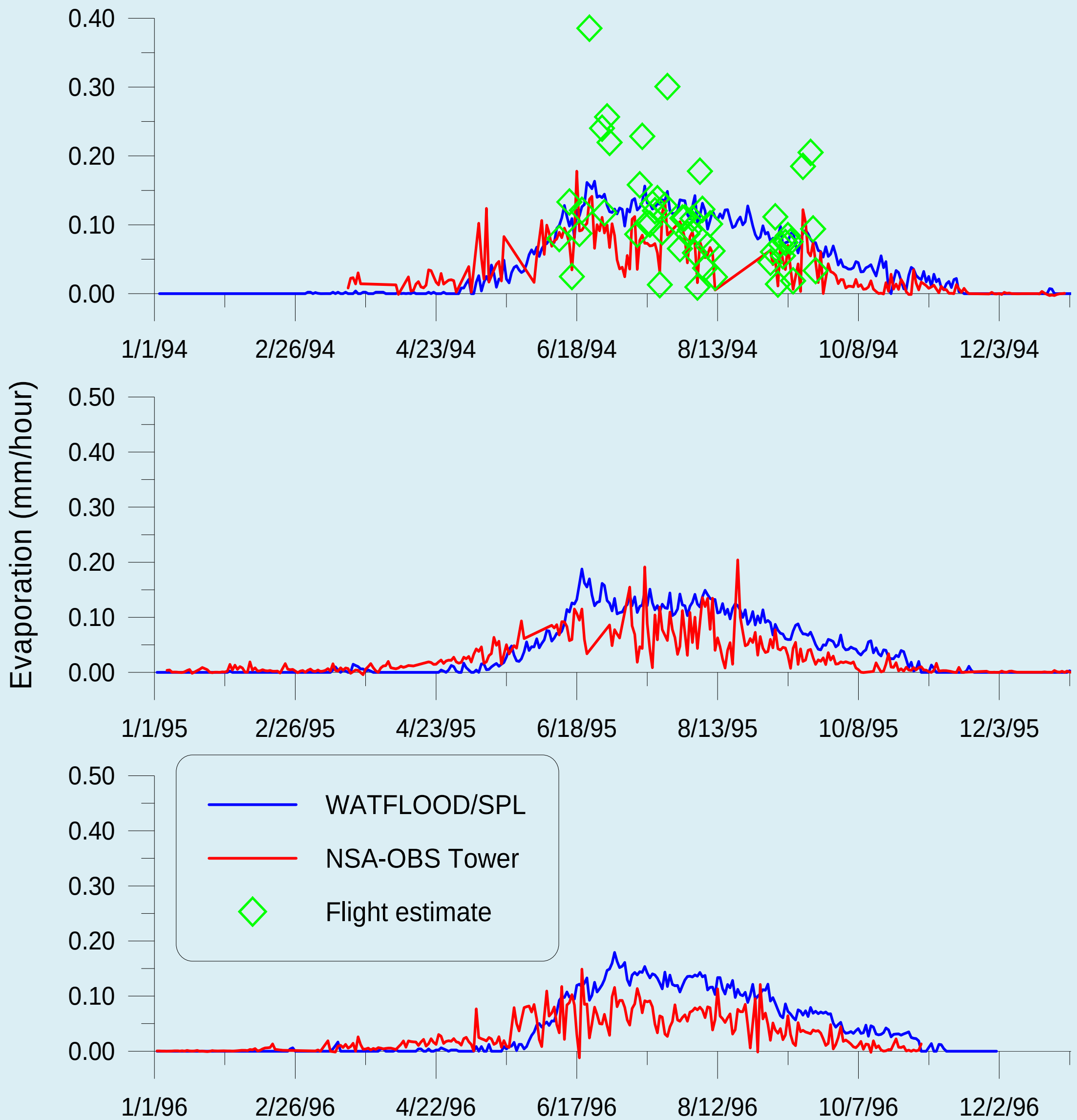


Field data provided by Joachim Gurtz & Massimiliano Zappa
Analysis by Shari Carlaw



Evaporation comparison for the BOREAS SSA-OBS Tower Site - eddy correlation method

By Todd Neff



Evaporation comparison for the BOREAS NSA-OBS Tower Site

By Todd Neff

WATFLOOD Tracers (Trish Stadnyk's stuff)

Tracer 0

Sub-basin separation

Tracer 1

Glacier melt separation

Tracer 2

Land-cover separation

Tracer 3

Rain-on-stream tracer

Tracer 100

Baseflow separation

Tracer 4

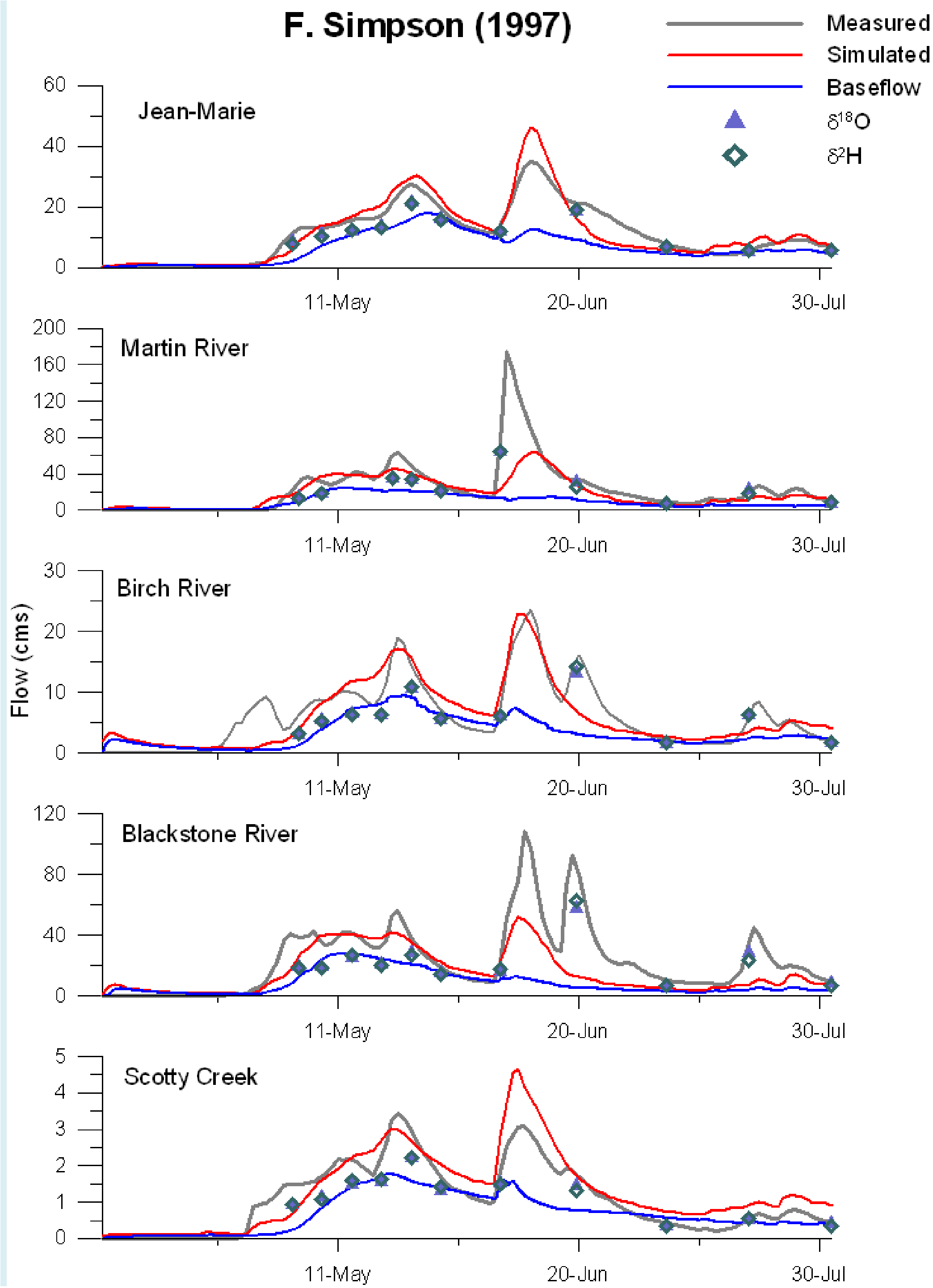
Flow separation

surface
interflow
baseflow

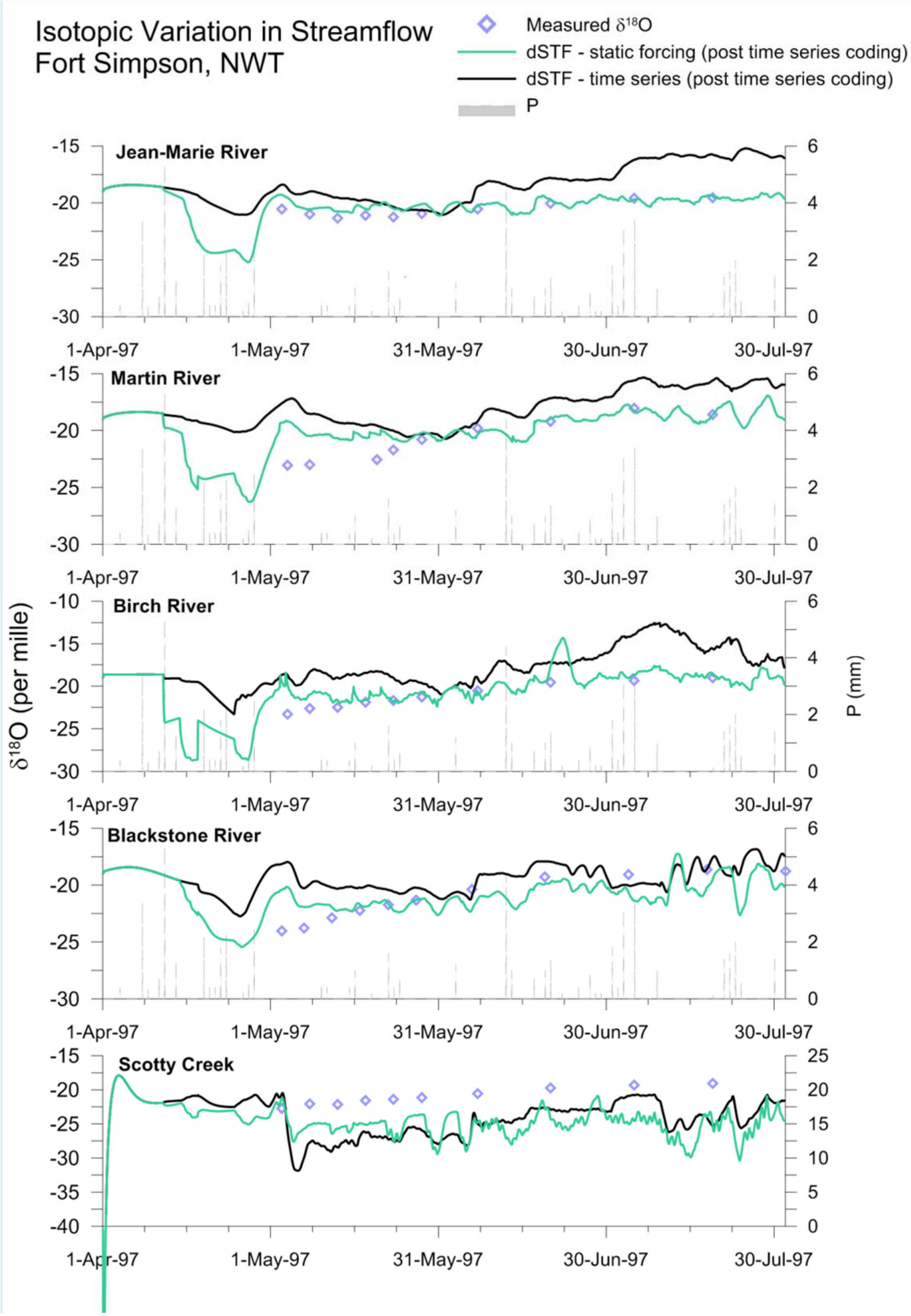
Tracer 5

Flow & Snow-melt

surface + surface melt
interflow + melt drainage
baseflow + interflow melt drainage



E.G. Baseflow has been compared to isotope analysis of streamflow sources



An isotope fractionation model has been embedded in WATFLOOD so $\delta^{18}O$ can be calculated and compared to observed $\delta^{18}O$ (also $\delta^{2}H$ now)

The isotope signature is affected by the proportion that water is or is not exposed to evaporation as O^{18} is not evaporated at the same rate as O^{16}

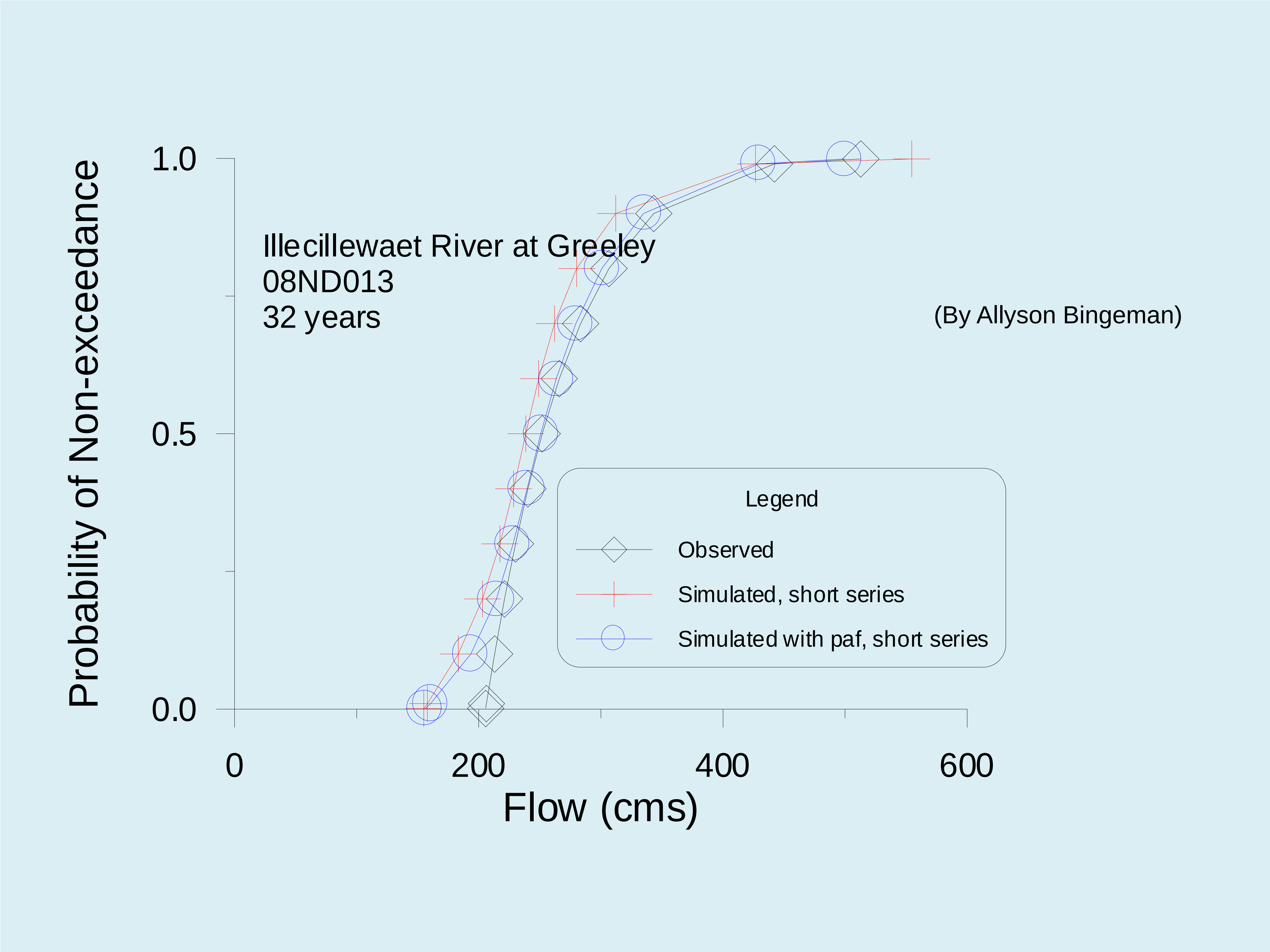
If computed and observed $\delta^{18}O$ are close, it ensures that the model`s mass balance is ok and that the GW portion of the flow is correct.

The WSC is collecting water samples for isotope analysis so this data can be used for modelling in the future.

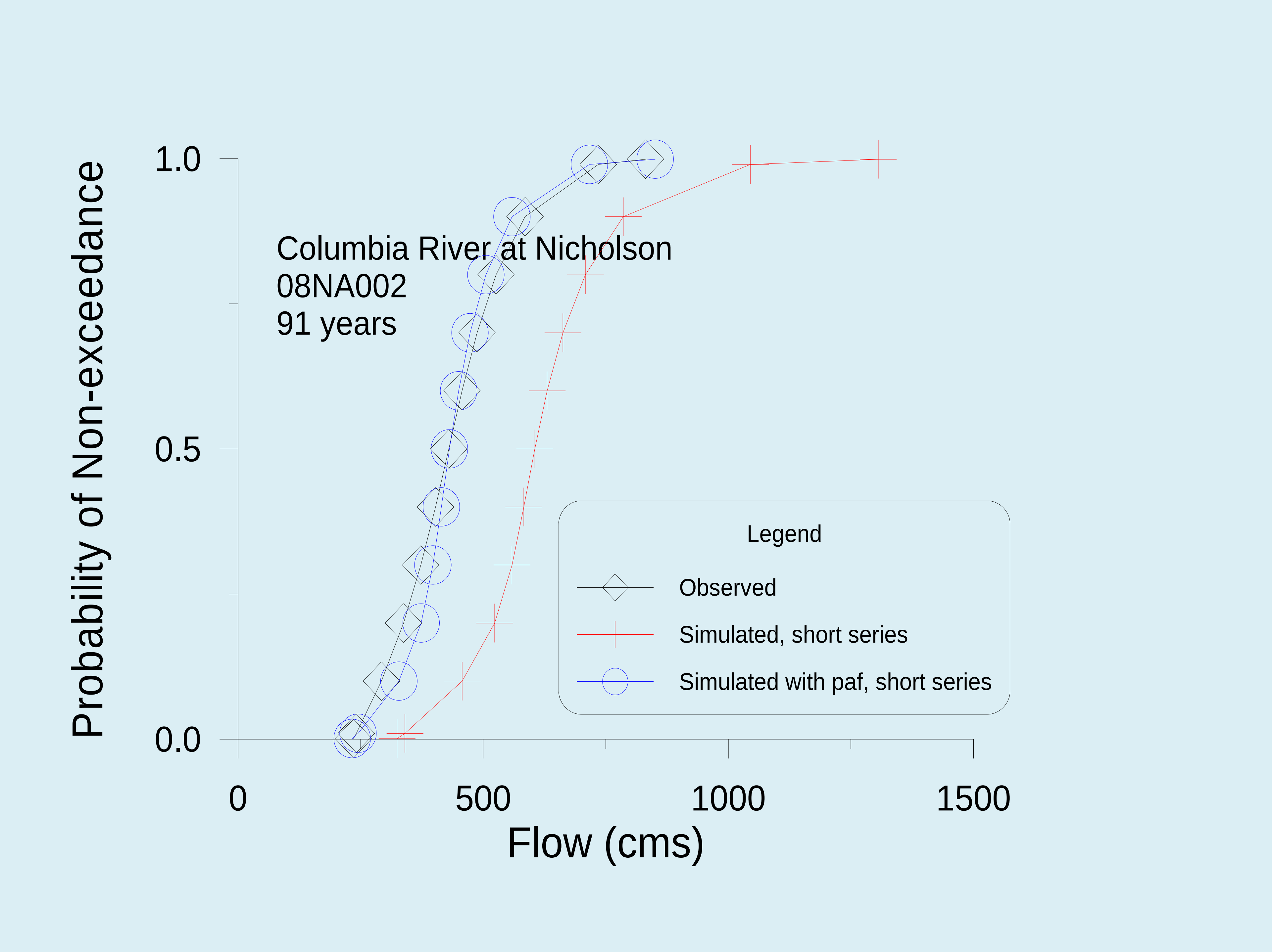
This is a 4 year pilot project 2013-2017

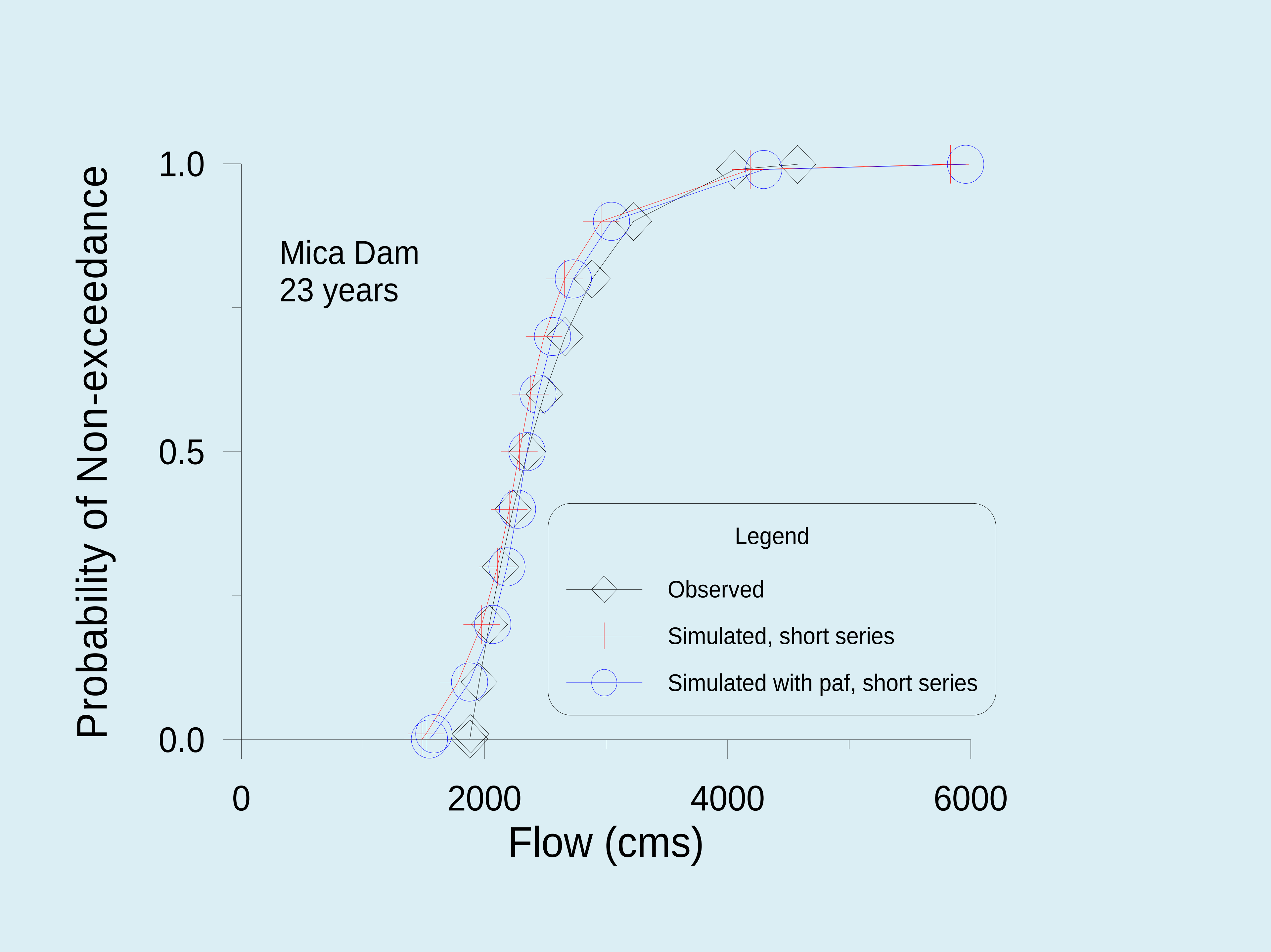
Other checks can be made:

- frequency analysis of observed & computed data can be compared



Illecillewaet River at Greeley
08ND013
32 years
(By Allyson Bingeman)
Probability of Non-exceedance
1.0
0.5
0.0
0
200
400
600
Flow (cms)
Legend
Observed
Simulated, short series
Simulated with paf, short series


Columbia River at Nicholson
08NA002
91 years
Probability of Non-exceedance
1.0
0.5
0.0
0
500
1000
1500
Flow (cms)
Legend
Observed
Simulated, short series
Simulated with paf, short series


Mica Dam
23 years
Probability of Non-exceedance
Flow (cms)
0.0
0.5
1.0
0
2000
4000
6000
Legend
Observed
Simulated, short series
Simulated with paf, short series

- You can **NEVER-EVER** eliminate errors of computed flows due to the areal variability of precipitation!!!!!!!!

- You can reduce errors by improving the representation of the watershed (e.g. landcover/soil based gru’s)

and

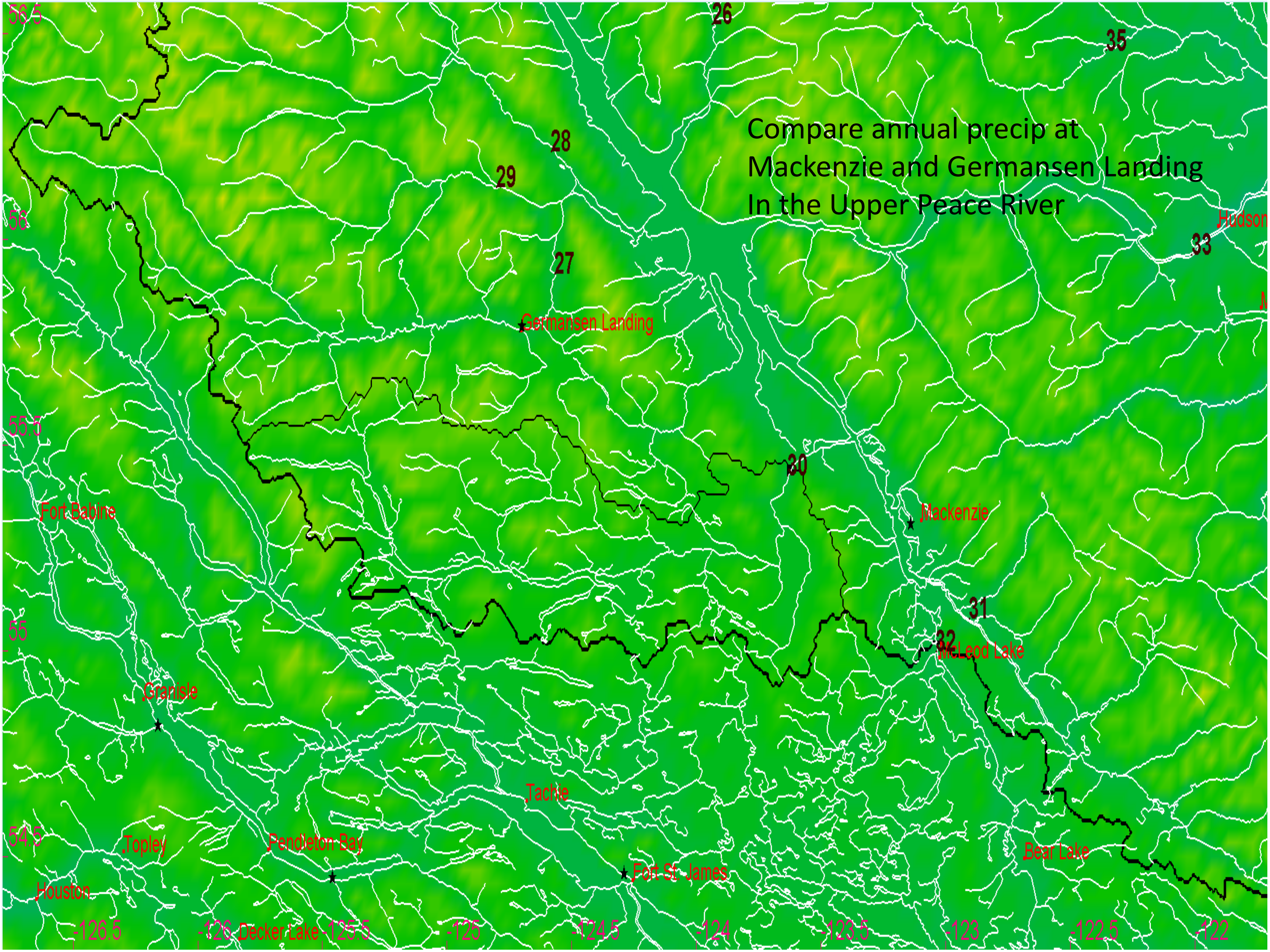
- Model improvement (e.g. lapse rates, lake evaporation, etc.)

UltraEdit - [Y:\spl\MRB22\ragmet_recl.txt]

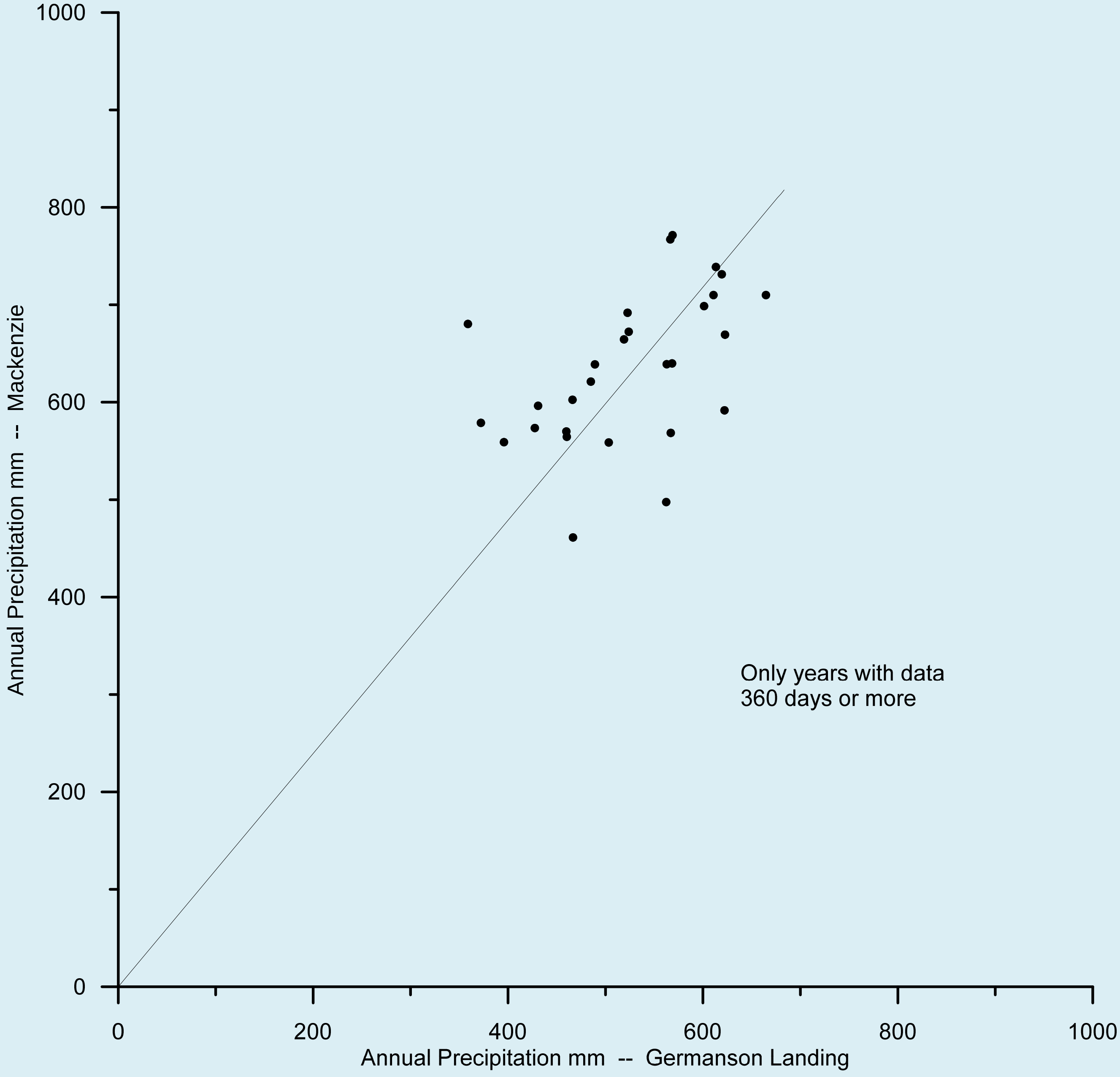
Quality of the precip data: # records / year

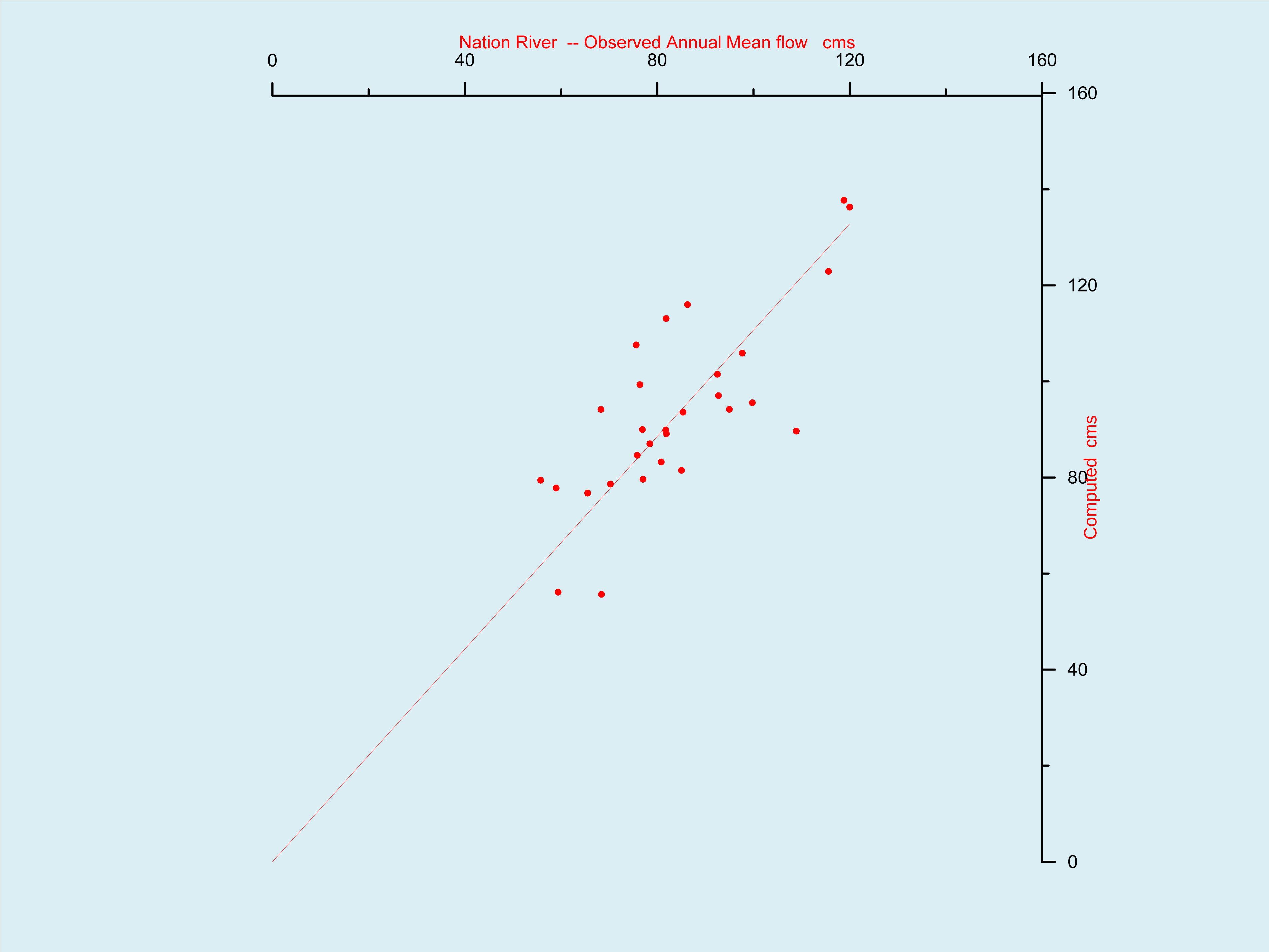
ID	BLUE_RIVE	MICA_DAM	FORT_ST_J	GERMANSEN	MACKENZIE	TAYLOR_FL	DEASE_LAK	FORT_NELS	MUNCHO_LA	ATLIN	no_data	HERSCHEL_	KLONDIKE	MAYO_A	OGILVIE_R	OLD_C
1	0	0	366	353	0	0	366	366	0	0	0	0	0	366	0	
2	0	0	365	360	0	0	365	365	0	0	0	0	0	365	0	
3	0	121	365	316	0	0	365	365	0	0	0	0	0	365	0	
4	0	363	365	365	0	0	365	365	0	15	0	0	0	365	0	
5	0	366	366	366	0	0	366	366	0	176	0	0	0	366	0	
6	0	365	365	365	0	0	365	365	0	0	0	0	0	365	0	
7	0	364	365	365	0	0	365	365	0	28	0	0	145	365	0	
8	0	365	365	365	0	0	365	365	0	346	0	0	151	365	0	
9	0	366	366	366	0	0	366	366	0	359	0	0	252	366	0	
10	31	365	365	365	0	0	365	365	0	360	0	0	193	365	0	
11	365	365	365	365	0	0	365	365	215	352	0	0	254	365	0	
12	365	364	365	365	327	0	365	365	332	354	0	0	292	365	44	
13	366	366	366	366	366	0	366	366	363	284	0	0	337	366	116	
14	365	365	365	365	365	0	365	365	365	150	0	0	315	365	363	
15	365	365	365	365	365	0	365	365	322	365	0	80	227	365	264	
16	365	363	365	365	365	0	365	365	286	334	0	86	162	365	235	
17	366	366	366	366	366	0	366	366	327	366	83	0	157	366	126	
18	365	365	365	365	365	0	365	365	329	365	334	0	200	365	187	
19	365	365	365	365	365	0	365	365	347	365	358	0	129	365	207	
20	335	365	365	335	365	0	365	365	164	365	334	0	126	328	167	
21	366	366	366	366	365	0	366	366	201	336	338	0	220	366	250	
22	365	365	365	365	365	0	365	365	358	335	247	0	256	365	201	
23	362	364	365	365	365	0	365	365	360	365	31	0	256	365	312	
24	365	361	365	365	365	0	365	365	365	365	0	0	219	363	295	
25	366	280	366	364	365	0	366	365	362	366	0	0	185	366	321	
26	365	182	365	365	364	0	365	365	362	365	0	0	198	365	321	
27	365	290	365	365	363	0	365	365	305	365	0	0	174	365	286	
28	365	[illegible]	365	[illegible]	357	0	365	365	363	365	0	0	189	365	201	
29	365	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	203	366	253	
30	365	353	365	365	358	0	365	365	365	365	0	0	199	335	247	
31	365	361	365	365	360	0	365	365	365	363	0	0	243	362	314	
32	365	359	365	365	365	0	365	364	361	365	0	0	214	365	365	
33	366	360	353	366	366	0	358	347	365	366	0	0	271	365	357	
34	365	365	364	365	365	0	328	365	365	365	61	0	316	361	354	
35	365	364	365	365	105	0	342	365	365	365	307	0	350	365	287	
36	365	365	365	365	297	0	365	362	365	365	365	0	327	31	283	
37	366	366	366	366	363	0	351	350	365	366	356	0	337	357	304	
38	365	364	363	365	351	0	365	350	365	365	201	0	356	363	354	
39	365	363	365	365	357	0	365	365	353	365	205	0	341	364	318	
40	365	361	365	365	358	0	365	365	365	365	313	0	321	365	256	
41	366	366	366	364	359	0	359	366	365	366	223	0	357	366	175	
42	364	358	365	362	361	0	365	365	329	334	158	0	250	365	279	
43	335	358	365	363	304	0	294	365	305	362	192	0	282	365	230	
44	365	363	365	365	362	0	264	365	334	365	109	0	227	365	227	
45	366	302	366	366	365	0	290	366	366	335	112	96	349	366	345	
46	365	359	365	365	365	0	284	365	365	365	46	208	354	365	300	
47	365	361	365	365	364	0	292	365	365	365	33	242	343	364	277	
48	319	338	365	355	356	0	177	365	329	354	0	0	51	365	49	
49	326	324	365	360	360	0	71	366	297	339	0	0	0	366	0	
50	299	334	365	365	360	0	0	365	206	352	0	186	0	365	0	
51	365	322	365	365	206	0	0	365	88	357	0	282	30	365	0	
52	360	354	365	365	318	0	0	365	339	362	0	305	0	365	0	
53	362	353	340	365	362	0	0	316	356	346	0	307	0	364	0	

For Help, press F1 | Ln 5, Col 265, C0 | DOS | Mod: 19/05/2016 10:0 | File Size: 49419 | INS | CAP

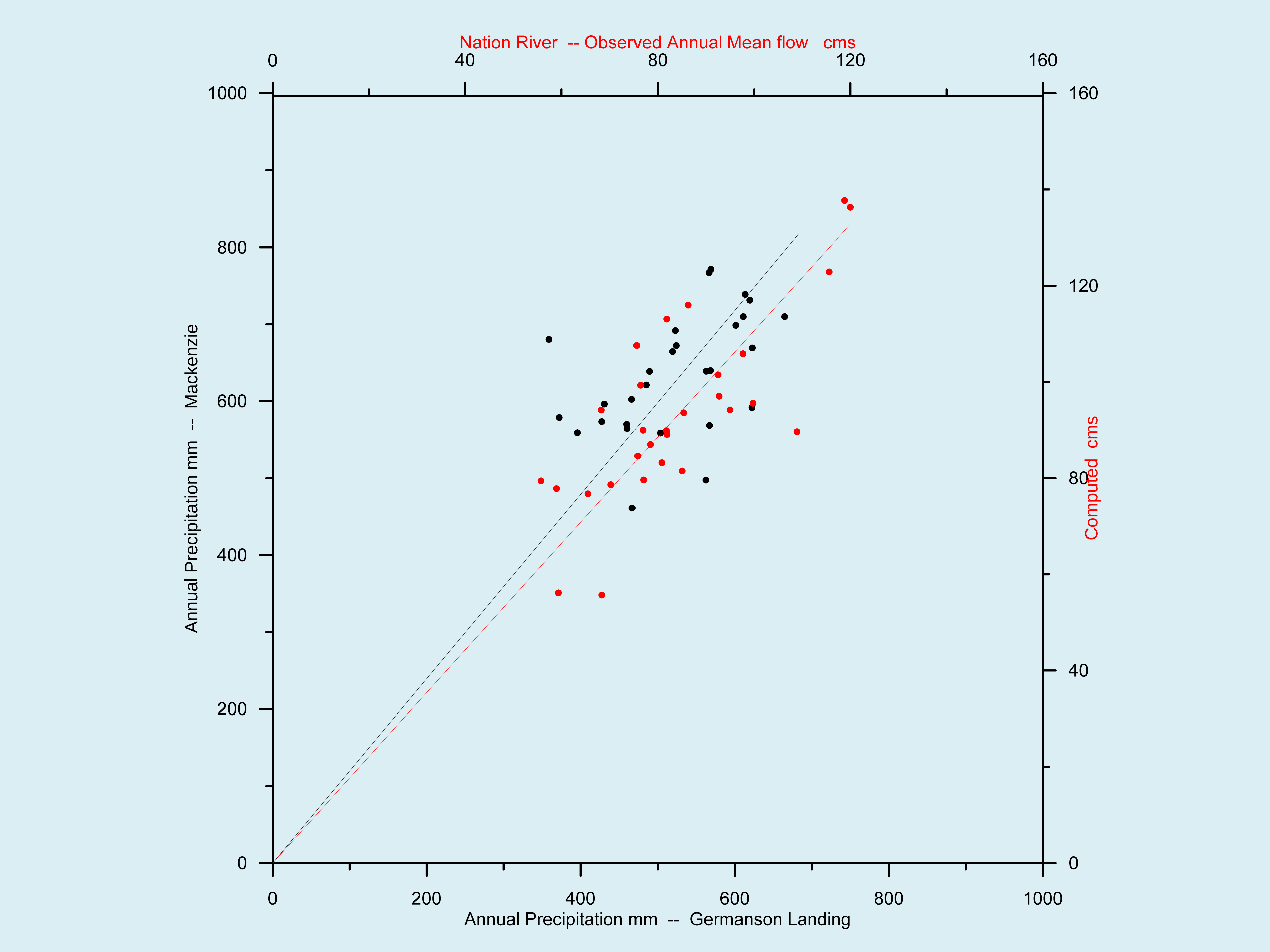

Compare annual precip at
Mackenzie and Germansen Landing
In the Upper Peace River
56.5
56
55.5
55
54.5
26
35
28
29
27
33
30
31
32
Germansen Landing
Mackenzie
McLeod Lake
Hudson
Fort Babine
Granisle
Tachie
Topley
Pendleton Bay
Fort St. James
Bear Lake
Houston
-126.5
-126
Decker Lake
-125.5
-125
-124.5
-124
-123.5
-123
-122.5
-122

Plot the annual precipitation for 2 neighboring stations



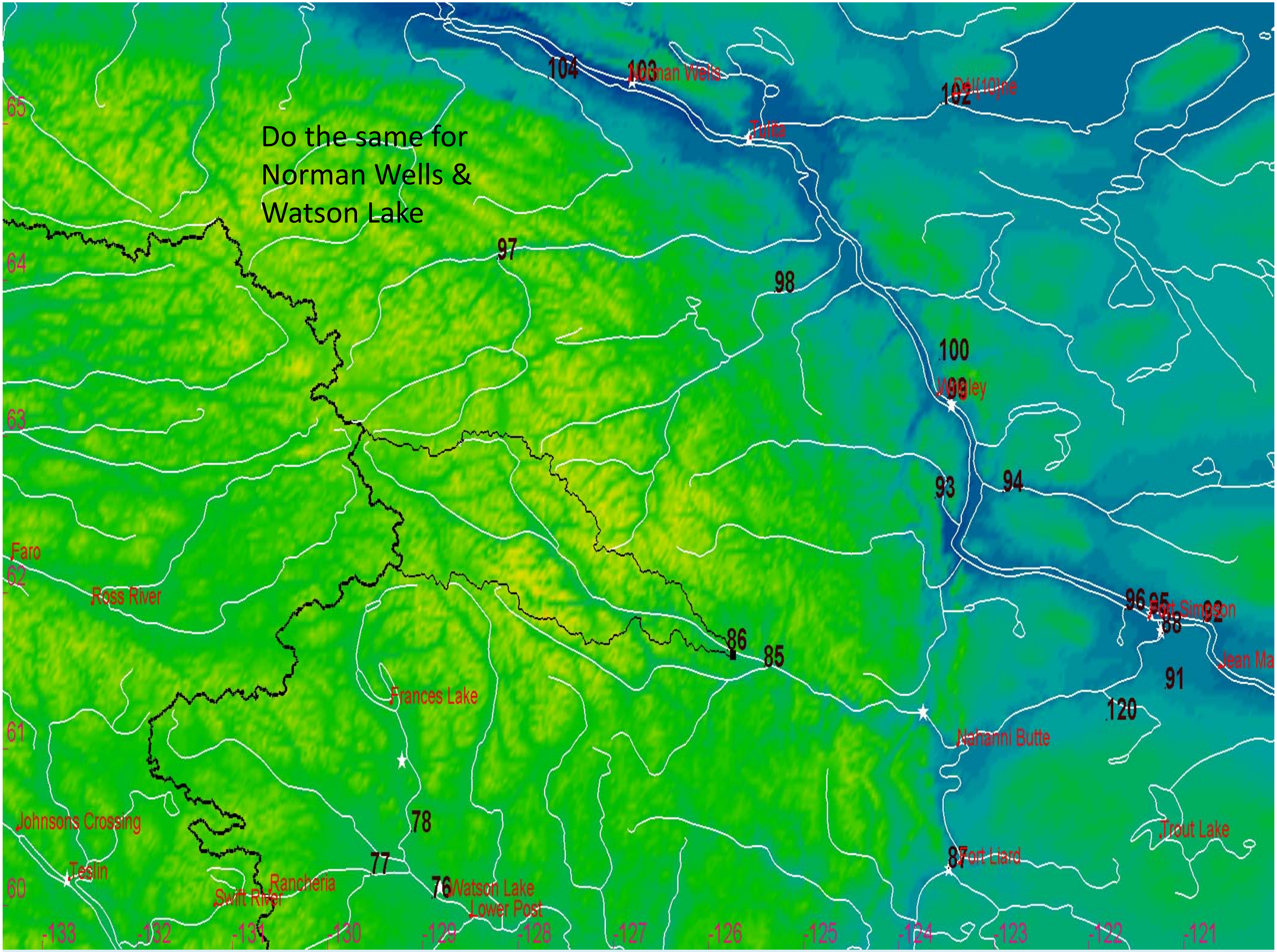


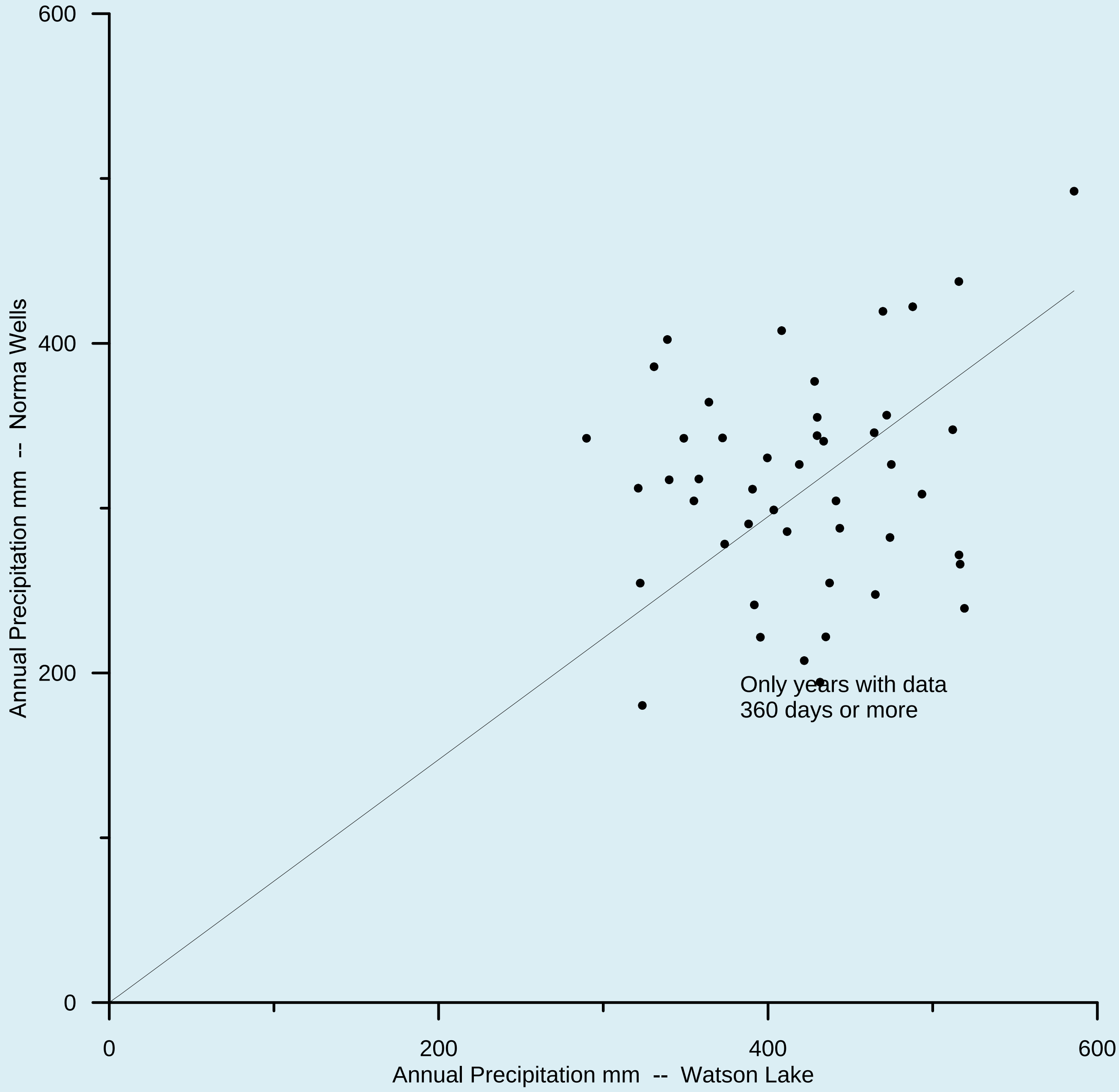
Nation River -- Observed Annual Mean flow cms
0
40
80
120
160
Computed cms

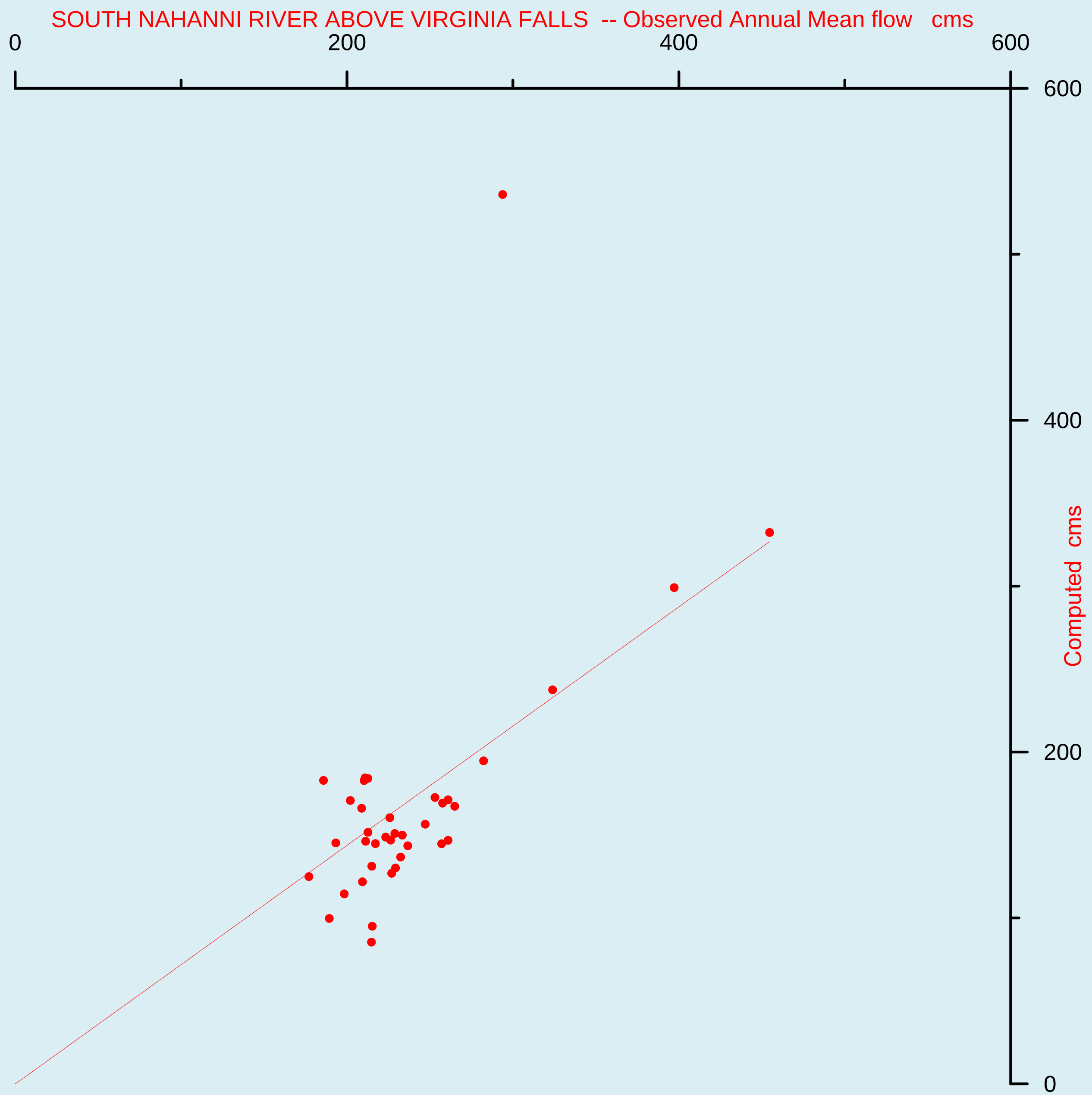


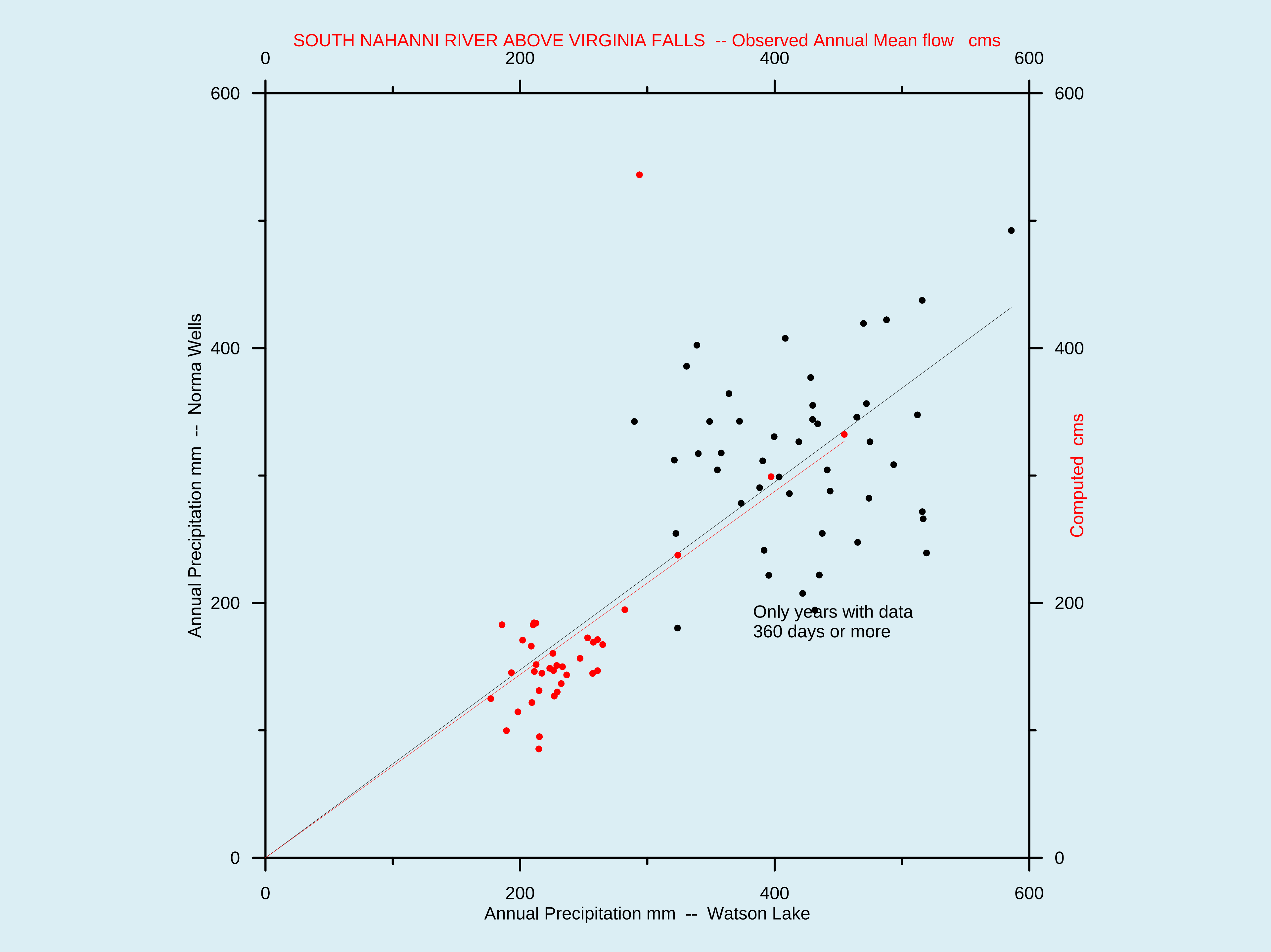
Nation River -- Observed Annual Mean flow cms
0
40
80
120
160
1000
800
600
400
200
0
160
120
80
40
0
Annual Precipitation mm -- Mackenzie
Computed cms
0
200
400
600
800
1000
Annual Precipitation mm -- Germanson Landing

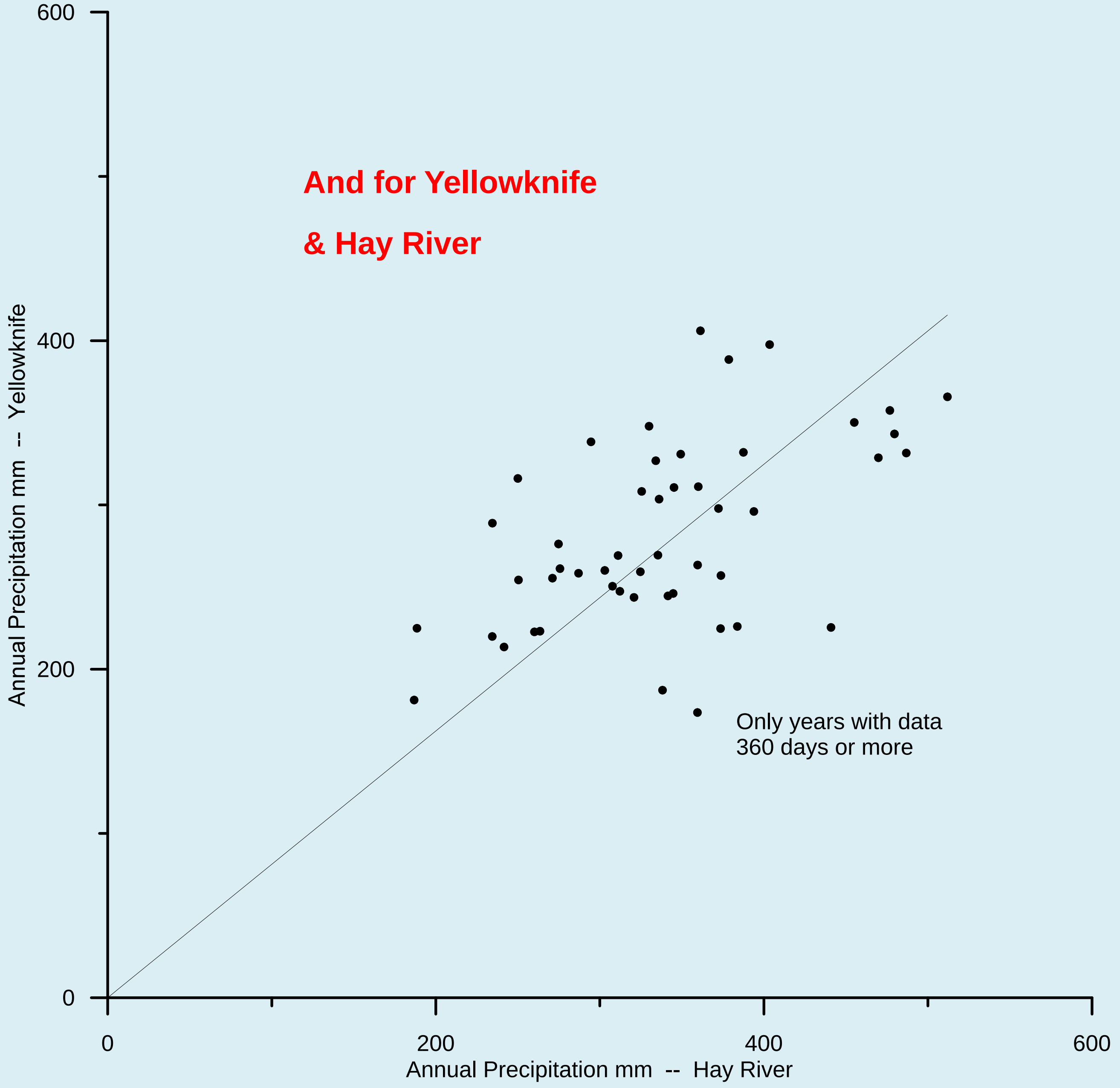
Do the same for Norman Wells & Watson Lake




600
400
200
0
Annual Precipitation mm -- Norma Wells
Only years with data
360 days or more
0
200
400
600
Annual Precipitation mm -- Watson Lake


SOUTH NAHANNI RIVER ABOVE VIRGINIA FALLS -- Observed Annual Mean flow cms
0
200
400
600
600
400
200
0
Computed cms


SOUTH NAHANNI RIVER ABOVE VIRGINIA FALLS -- Observed Annual Mean flow cms
0
200
400
600
Annual Precipitation mm -- Norma Wells
Computed cms
Only years with data
360 days or more
Annual Precipitation mm -- Watson Lake


And for Yellowknife
& Hay River
Only years with data
360 days or more
Annual Precipitation mm -- Yellowknife
Annual Precipitation mm -- Hay River
0
200
400
600
0
200
400
600

This should serve to lower expectations a bit!

Coffee maybe?