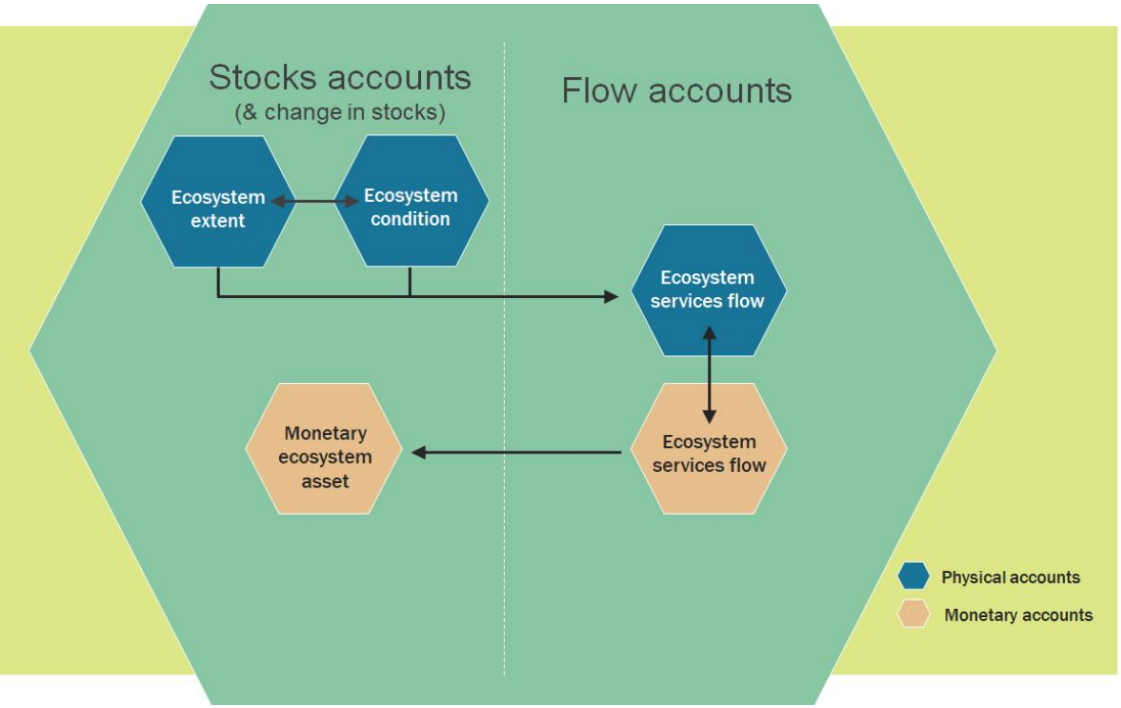
A framework for developing an environmental accounting system for freshwater ecosystem services in the Waikato Region

Richard T. Yao and David J. Palmer

Contributed Papers Session – Stream 3 Enviro Econ, NZARES Conference, Nelson (1 Sep 2022)

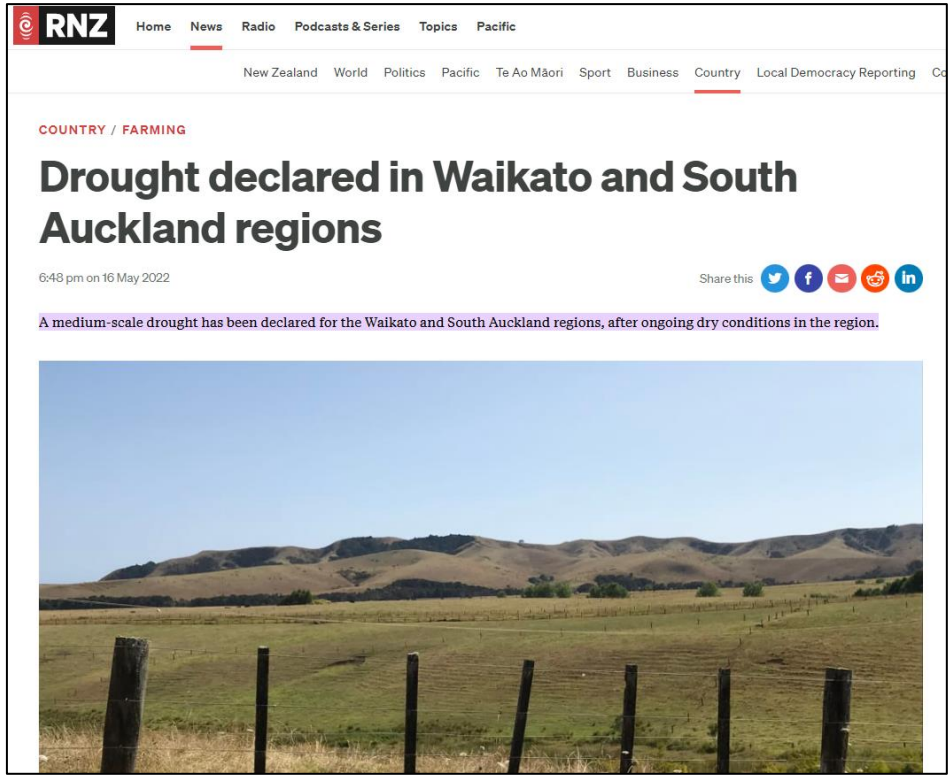


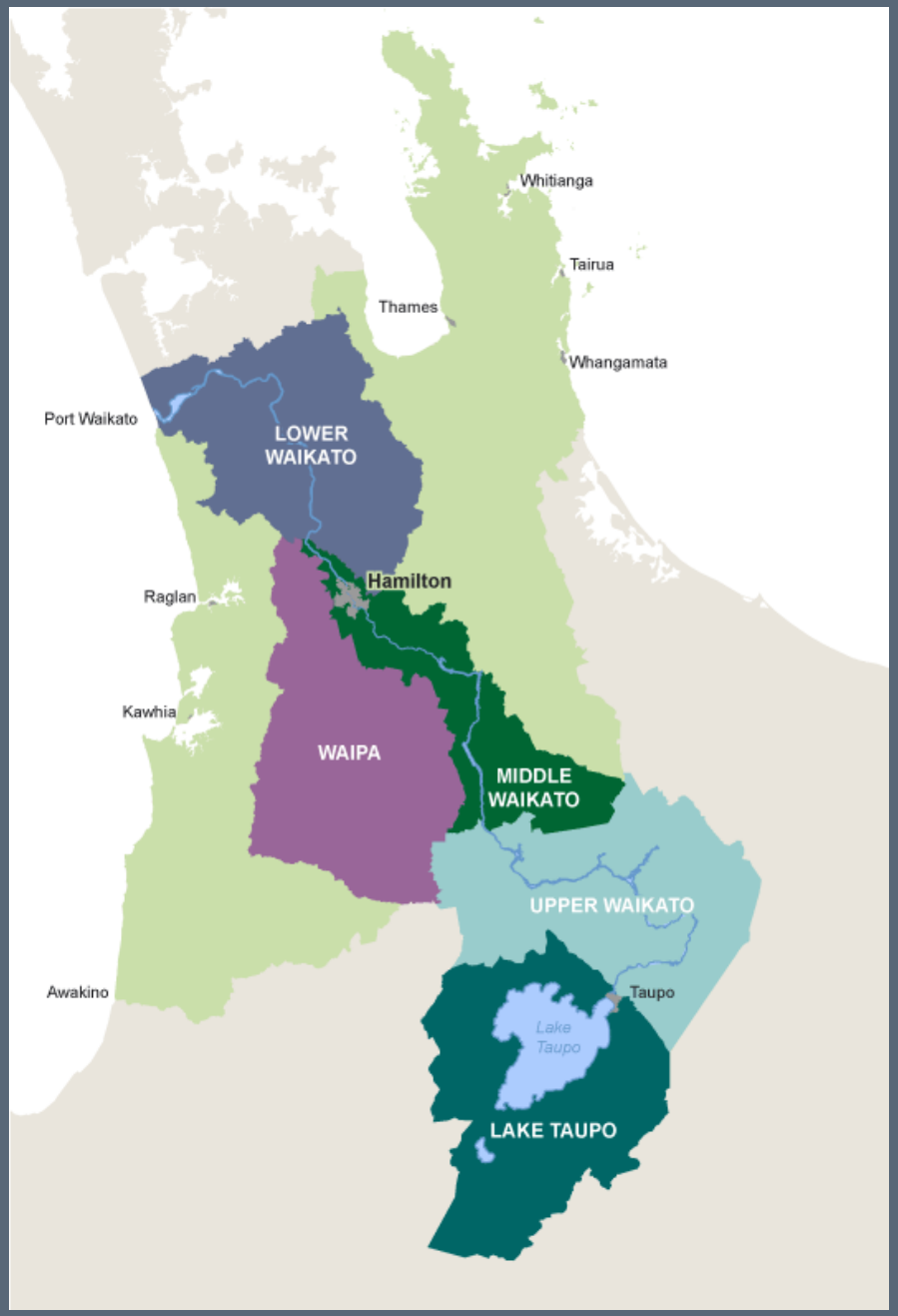
Outline

- Overview
- Methods
- The study site
- Results
- Conclusions and where to next

Study motivation and aims

- Freshwater is important to the people, the environment, and the economy
- Freshwater availability matters
  - Too much water – flooding, water logging
  - Lack of water – drought, water stress
- Land use change - associated with water availability
  - Pasture to forestry – decrease in water yield (Davie & Fahey 2005)
  - Forestry to pasture increases flooding (Woods et al. 2010)
- This study aims to:
  - evaluate the impacts of land use change on water availability in the Waikato region
  - develop a framework to quantify freshwater regulation values and incorporate into a pilot environmental accounting system





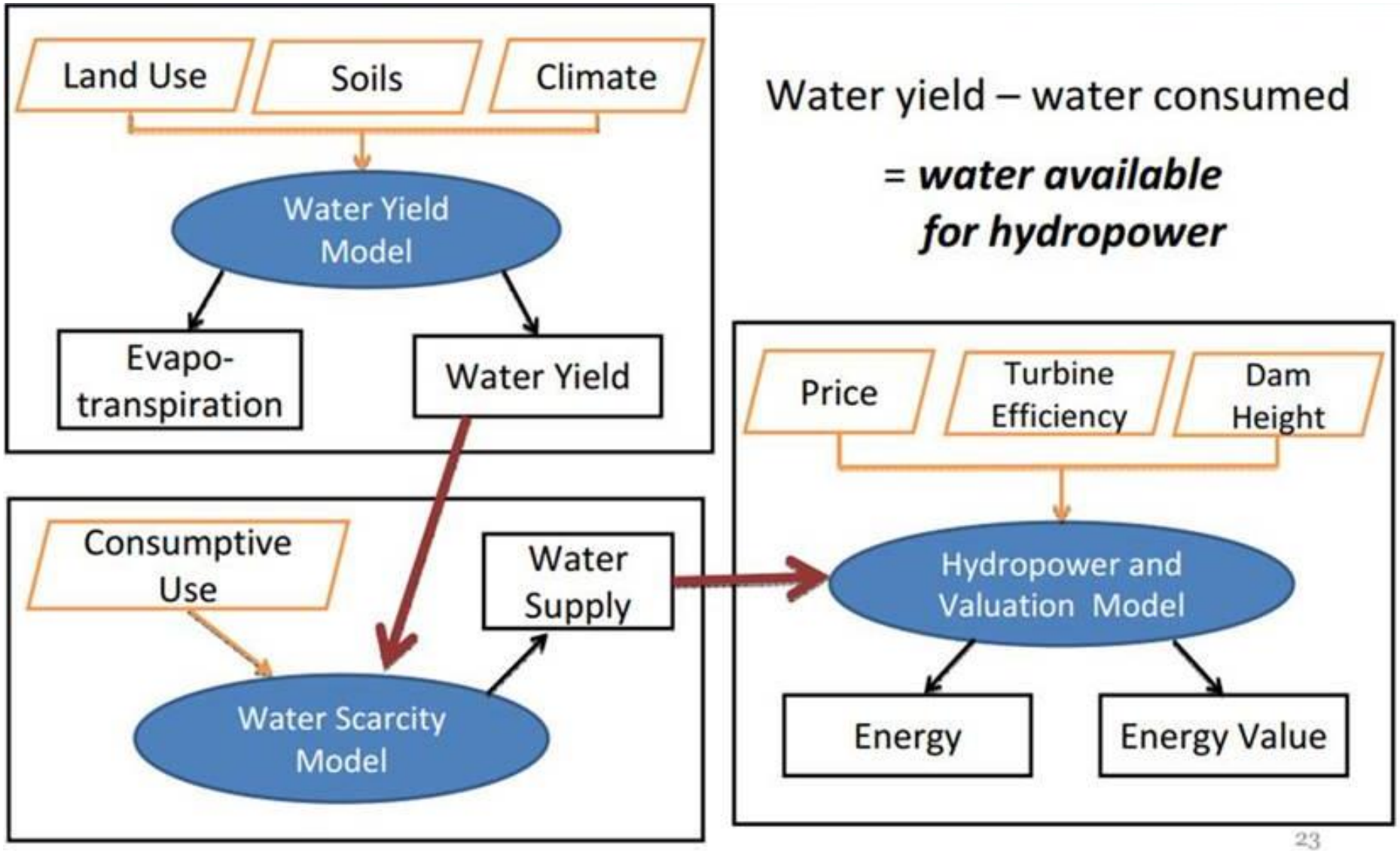
Background

- Freshwater Ecosystem Services Project – Phase 4
  - Scion-WRC long-term research partnership
  - improve the visibility of freshwater non-market values in decision making
- Between 2002 & 2008, ~29,000 ha of forestry were converted to pasture in the Upper Waikato catchment (Archer et al. 2019)
- Many studies examined the impact of land use change on water quality (Trodahl et al. 2017)
  - limited studies on the impacts of land use change on water availability (Woods et al. 2010)
- MfE's Our Freshwater 2020 report recommended that knowledge gaps in our freshwater environment should be addressed by:
  - understanding and quantifying the benefits of freshwater
  - improving our understanding of the pressures on freshwater and their causes.

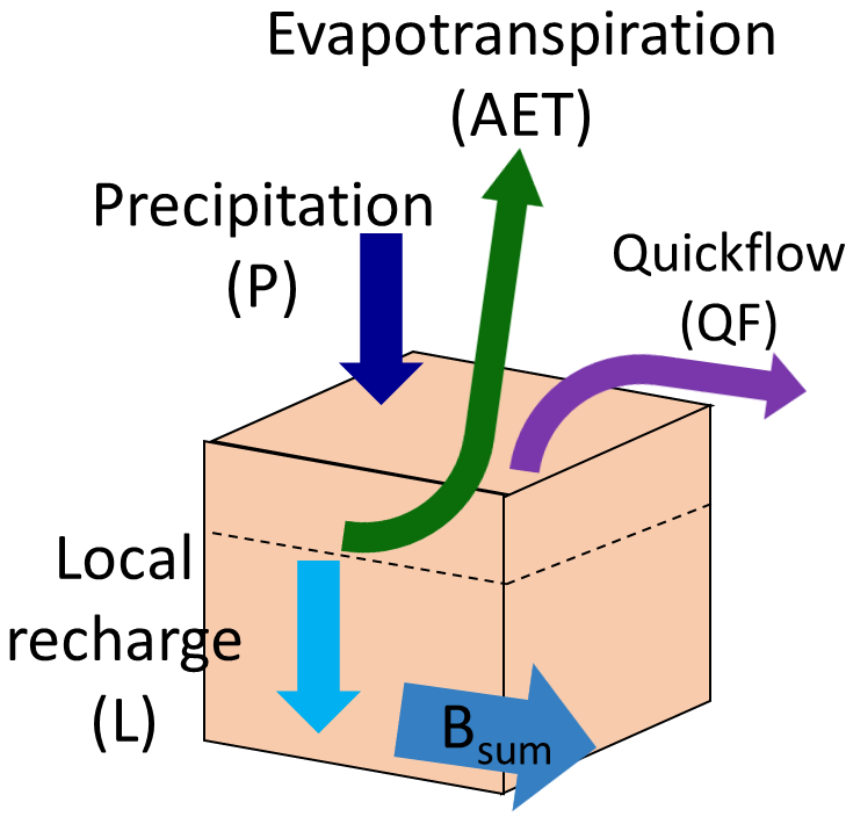
Method – spatial modelling

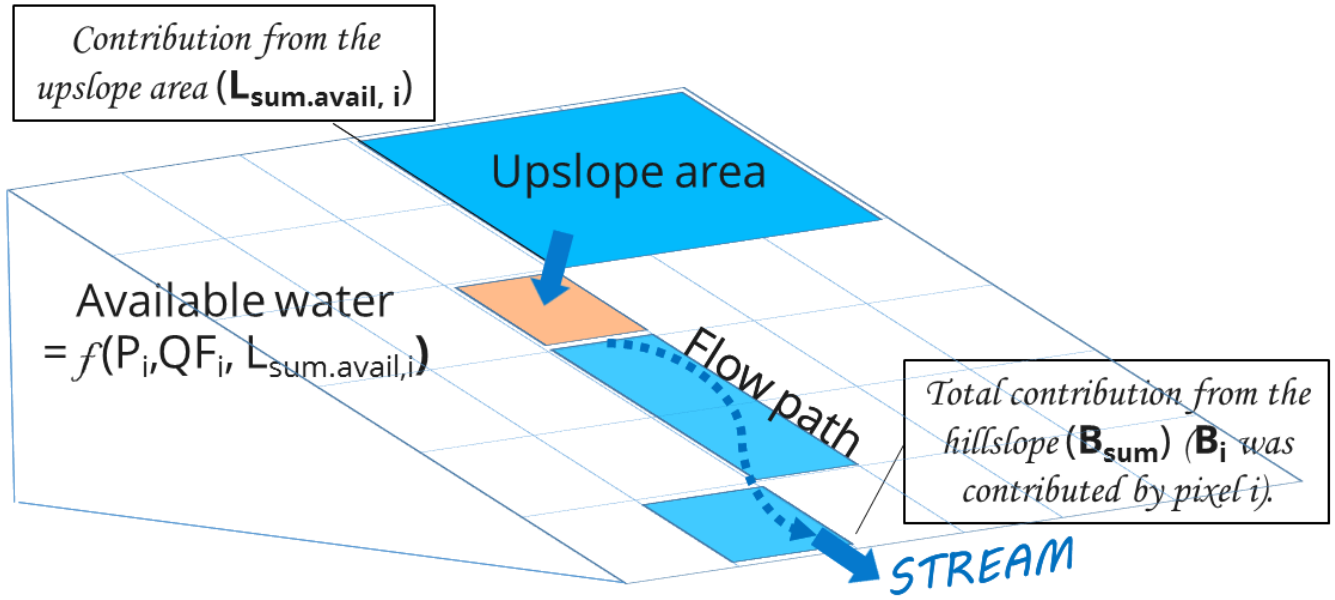
- InVEST – suite of spatial models for exploring how changes in ecosystem features are likely to alter the flow of ecosystem functions/services (e.g., water yield and local recharge)
  - Water Yield model – amount of water produced by a catchment
    - WY = precipitation less evapotranspiration
      - includes *hydropower* valuation
  - Seasonal Water Yield model – captures seasonal effects
    - Data include monthly rainfall, monthly ET, DEM & hydrological soil groups
    - Quantifies:
      - *Quickflow* (water runoff after short rain events)
      - *Local recharge* (water that becomes available as baseflow that supports dry-season river flows)

InVEST Water Yield and Hydropower Valuation model



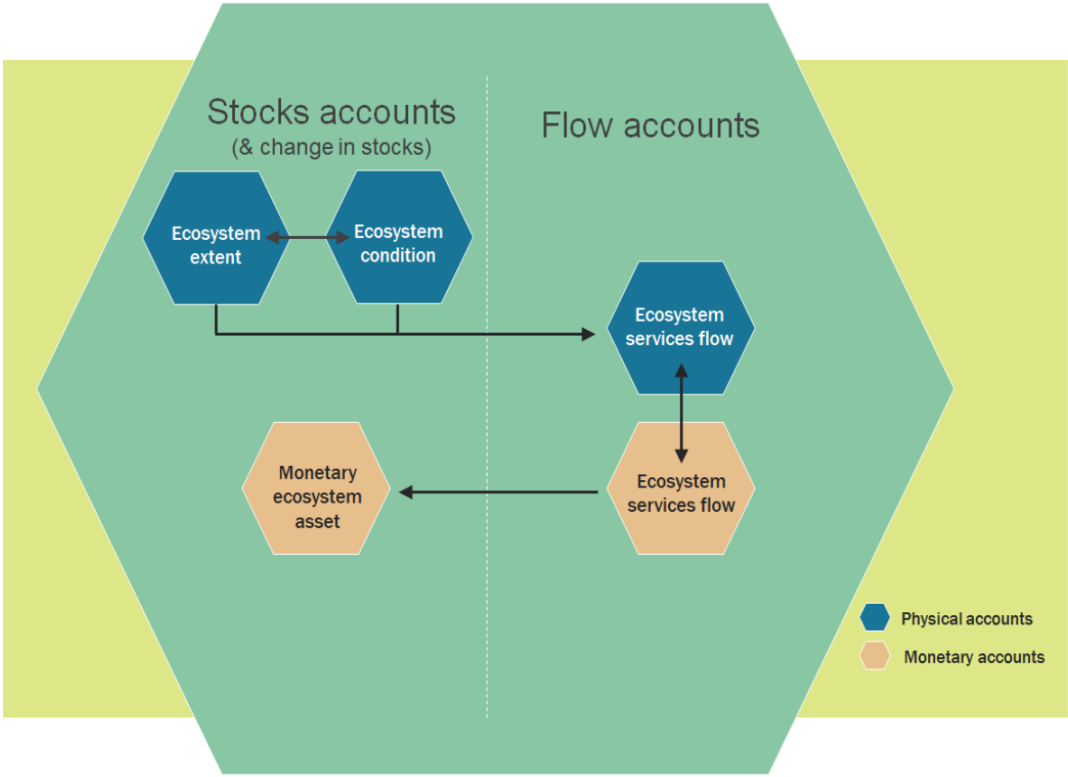
InVEST Seasonal Water Yield model





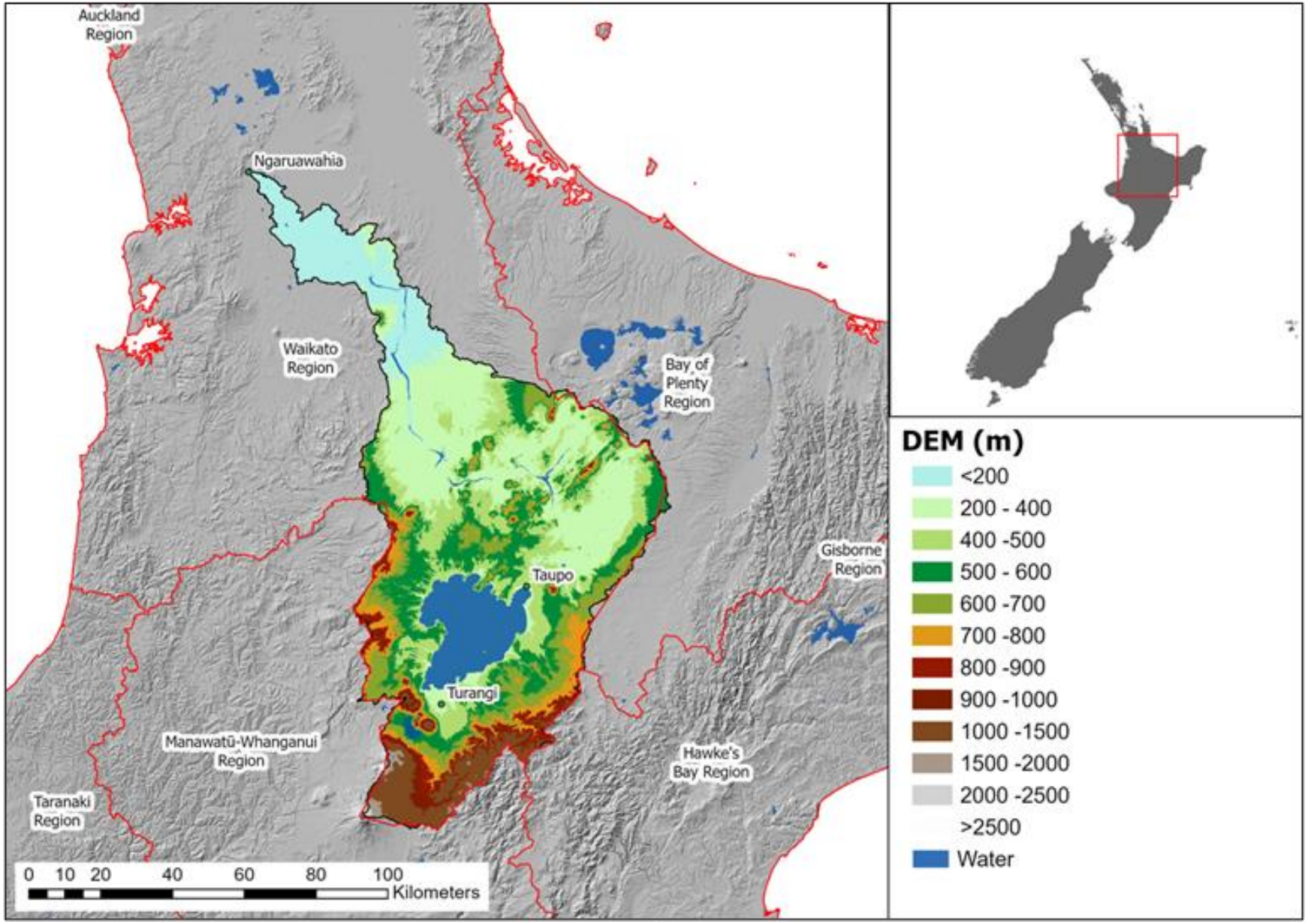
Method – ecosystem accounting

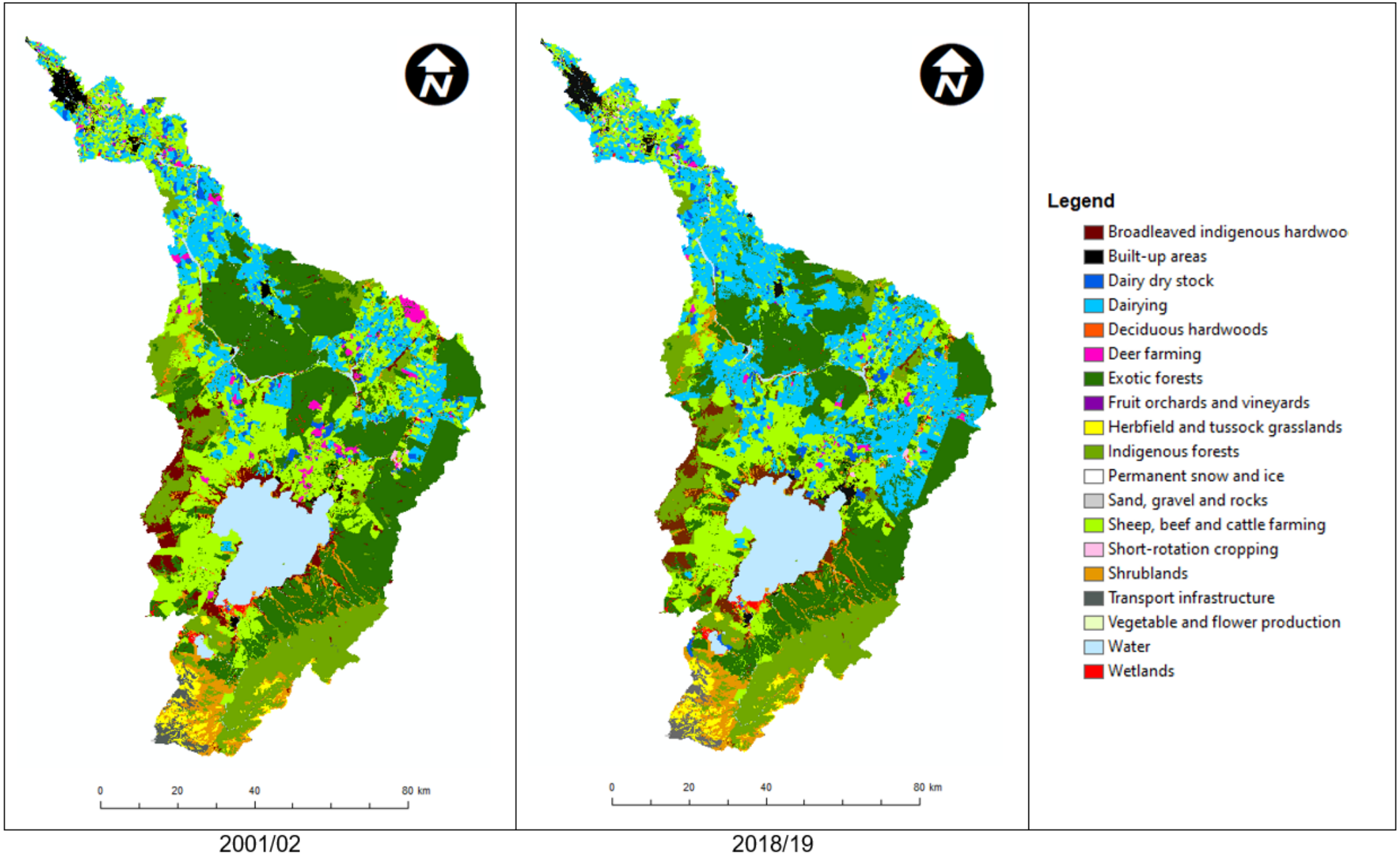
- Ecosystem accounting gained traction globally because of the vital role of natural resources in sustaining economic and human well-being
- Environmental damage is a threat to the economy but it's hardly counted in economic figures like the GDP
- SEEA-Ecosystem Accounting is an integrated statistical framework for organizing data about landscapes, measuring ES and linking this information to economic and other human activity
- Having a standardised, detailed values data can help improve managing water supply and demand, and adapting to extreme weather events
- Capacity Account provides the capacity of each land use class to potentially supply water flow regulation services



		Ecosystem Type (Land Use/Land Cover (LULC) Class)																			
		Broadleaved indigenous hardwoods	Built-up areas	Dairy dry stock	Dairying	Deciduous hardwoods	Deer farming	Exotic forests	Fruit orchards and vineyards	Herbfield and tussock grasslands	Indigenous forest	Sand, gravel, rocks	Transport infrastructure	Sheep, beef and cattle farming	Short-rotation cropping	Shrublands	Permanent snow and ice	Vegetable and flower production	Water	Wetlands	Total
Water yield ('000 m3/year)	Biophysical, climate & LULC 2001/02	30,042	10,895	10,506	75,633	1,792	9,949	229,839	380	29,861	158,010	867	463	170,230	1,320	57,831	20,485	296	33,446	3,354	845,199
	Biophysical, climate & LULC 2018/19	17,817	9,179	8,243	87,975	946	1,763	111,359	330	20,900	95,965	543	320	91,289	935	37,086	13,637	421	12,780	1,823	513,309
	Change in water yield (2018/19 less 2001/02)	-12,225	-1,717	-2,263	12,342	-846	-8,186	-118,480	-50	-8,961	-62,045	-324	-142	-78,941	-384	-20,745	-6,849	124	-20,666	-1,531	-331,890
	% change = [Change ÷ (2001/02)] X 100%	-40.69	-15.76	-21.54	16.32	-47.20	-82.28	-51.55	-13.10	-30.01	-39.27	-37.42	-30.80	-46.37	-29.12	-35.87	-33.43	41.96	-61.79	-45.64	-39.27
Quickflow ('000 m3/year)	Biophysical, climate & LULC 2001/02	2,215	1,225	783	5,960	842	556	11,932	37	7,076	7,297	213	412	12,632	206	5,488	8,573	47	74,197	3,874	143,564
	Biophysical, climate & LULC 2018/19	1,386	967	689	7,996	542	117	7,021	36	3,542	4,980	99	278	7,738	132	3,423	4,802	66	60,149	2,420	106,381
	Change in quickflow (2018/19 less 2001/02)	-829	-258	-95	2,036	-300	-439	-4,911	-1	-3,534	-2,317	-113	-134	-4,894	-74	-2,065	-3,771	19	-14,048	-1,455	-37,183
	% change = [Change ÷ (2001/02)] X 100%	-37.44	-21.03	-12.11	34.15	-35.60	-78.96	-41.16	-2.81	-49.94	-31.76	-53.36	-32.52	-38.74	-35.92	-37.63	-43.99	39.23	-18.93	-37.55	-25.90
Local recharge ('000 m3/year)	Biophysical, climate & LULC 2001/02	27,276	9,661	9,038	65,304	812	8,949	214,856	320	21,568	149,808	654	51	150,119	949	51,515	11,924	188	-7,165	-1,283	714,546
	Biophysical, climate & LULC 2018/19	15,703	8,176	6,827	71,400	262	1,489	100,103	256	15,817	89,662	442	42	76,526	630	32,605	8,834	255	-5,689	-1,276	422,061
	Change in local recharge (2018/19 less 2001/02)	-11,574	-1,485	-2,211	6,095	-551	-7,461	-114,754	-65	-5,751	-60,145	-212	-9	-73,593	-319	-18,910	-3,090	67	1,476	7	-292,485
	% change = [Change ÷ (2001/02)] X 100%	-42.43	-15.37	-24.46	9.33	-67.80	-83.37	-53.41	-20.20	-26.67	-40.15	-32.46	-16.81	-49.02	-33.64	-36.71	-25.92	35.86	-20.60	-0.52	-40.93
Baseflow ('000 m3/year)	Biophysical, climate & LULC 2001/02	27,968	9,815	9,332	67,644	1,130	9,138	218,907	337	21,690	151,354	661	51	153,875	1,011	52,630	12,089	200	19	0	737,851
	Biophysical, climate & LULC 2018/19	16,350	8,358	7,119	75,510	535	1,539	103,609	276	15,956	91,343	449	42	79,883	681	33,763	9,030	275	14	0	444,732
	Change in baseflow (2018/19 less 2001/02)	-11,619	-1,457	-2,213	7,866	-595	-7,599	-115,298	-62	-5,733	-60,011	-213	-9	-73,992	-330	-18,867	-3,058	75	-5	0	-293,119
	% change = [Change ÷ (2001/02)] X 100%	-41.54	-14.85	-23.71	11.63	-52.68	-83.16	-52.67	-18.28	-26.43	-39.65	-32.15	-16.81	-48.09	-32.66	-35.85	-25.30	37.66	-26.53	4.36	-39.73

Study area = 838,505 ha





2001/02

2018/19

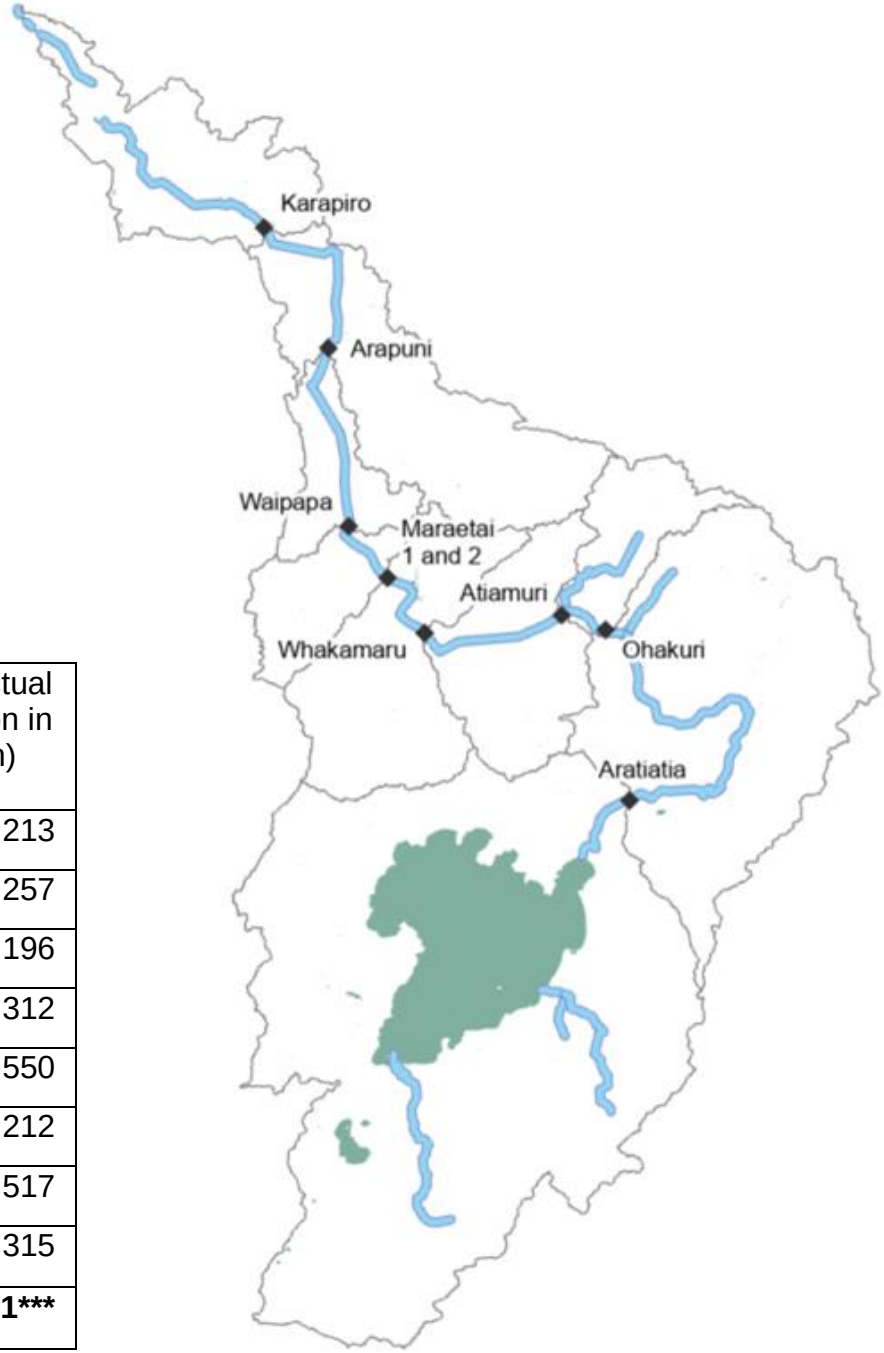
Study site ~838,505 ha

Land use change - 2001/02 & 2018/19

Land use	Area in 2001/02 (ha)	Area in 2018/19 (ha)	Change in area (ha)
Exotic forests	247,605	201,848	-45,757
Sheep, beef and cattle farming	190,037	162,466	-27,570
Indigenous forest	103,283	101,559	-1,724
Dairying	97,538	179,207	81,668
Water	69,236	69,199	-37
Shrublands	34,410	33,825	-585
Broadleaved indigenous hardwoods	29,829	29,361	-468
Dairy dry stock	14,575	15,580	1,006
Deer farming	11,914	3,639	-8,275
Built-up areas	11,670	13,589	1,919
Herbfield and tussock grasslands	11,642	11,642	0
Permanent snow and ice	7,794	7,787	-6
Wetlands	3,072	2,767	-305
Deciduous Hardwoods	2,042	1,745	-297
Short-rotation cropping	1,953	1,922	-31
Fruit orchards and vineyards	682	848	166
Sand, gravel, rocks	664	615	-49
Vegetable and flower production	456	801	345
Transport infrastructure	103	103	0
TOTAL	**838,505**	**838,505**	

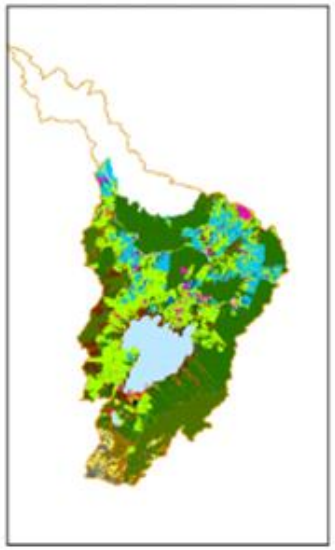
Sub-catchments and hydropower dams

- We used the InVEST module “DelineateIT” to identify the 8 hydropower sub-catchments
  - Waikato River Hydro Lakes
- Power stations have a production capacity of >4,000 GwH per year
  - ~13% of the total electricity supply of New Zealand

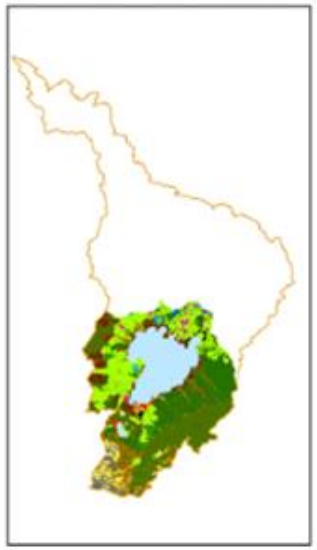


Item number	Hydropower dam	Average annual energy generation (GWh)*	Approximated actual energy generation in 2001/02 (GWh)	Approximated actual energy generation in 2018/19 (GWh)
1	Aratiatia	331	310	213
2	Ohakuri	400	375	257
3	Ātiamuri	305	286	196
4	Whakamaru	486	455	312
5	Maraetai 1 & 2	856	802	550
6	Waipapa	330	309	212
7	Arapuni	805	754	517
8	Karapiro	490	459	315
	TOTAL	**4,002**	**3,750****	**2,571*****

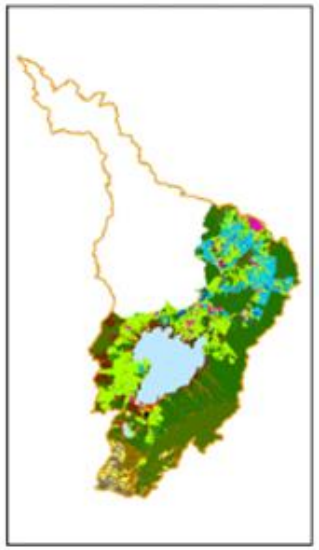
Land use distribution by sub-catchment 2001/02



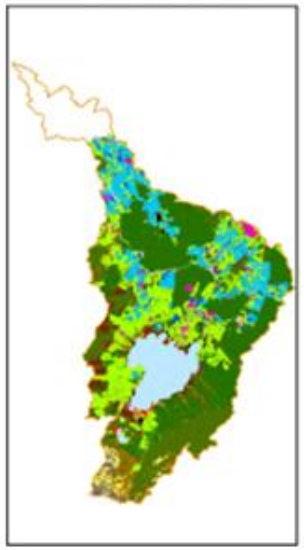
Arapuni



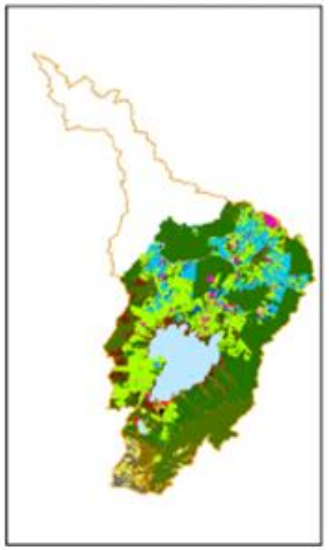
Aratiata



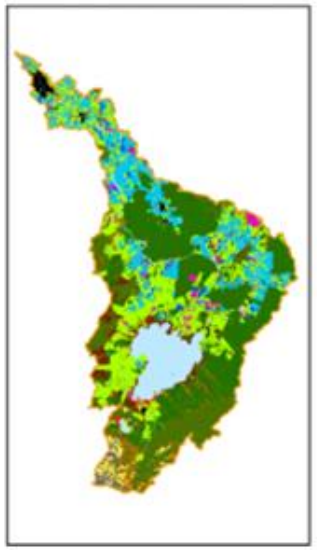
Atiamuri



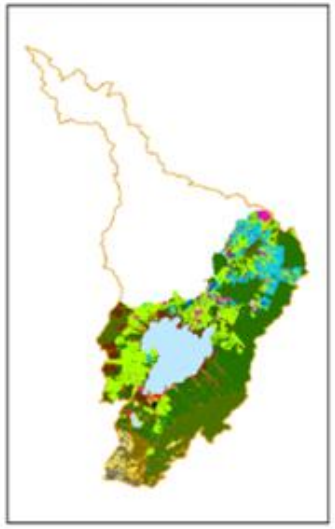
Karapiro



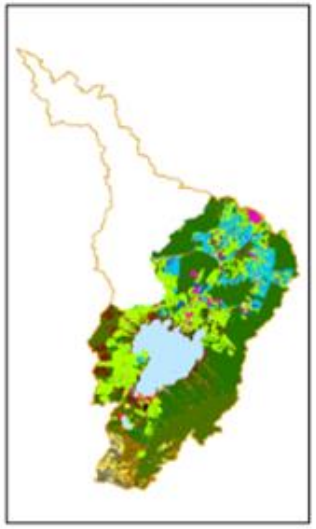
Maraetai 1&2



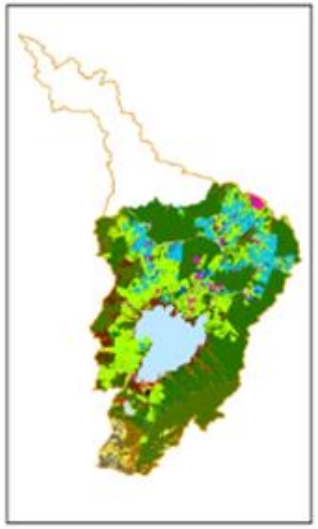
Ngaruawahia



Ohakuri

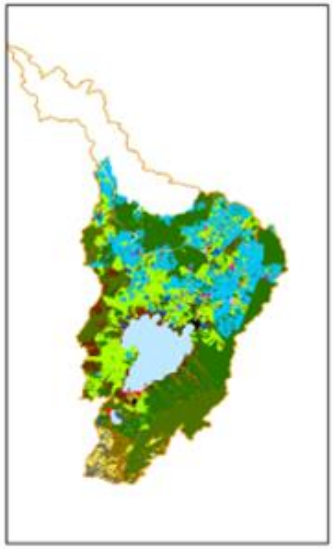


Whakamaru

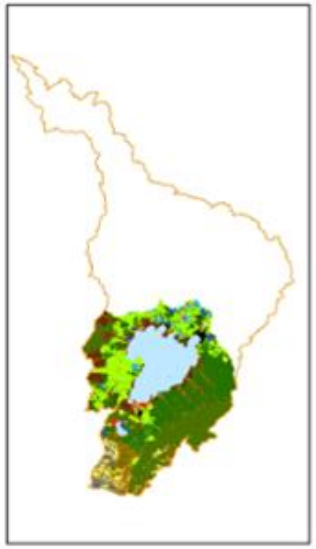


Waipapa

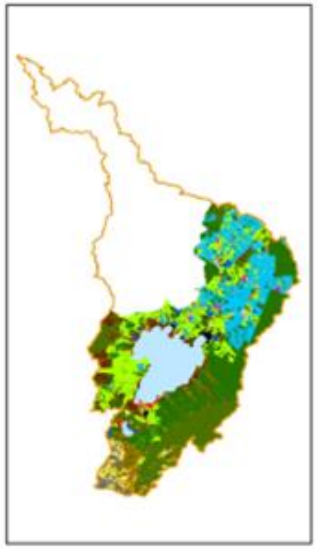
Land use distribution by sub-catchment 2018/19



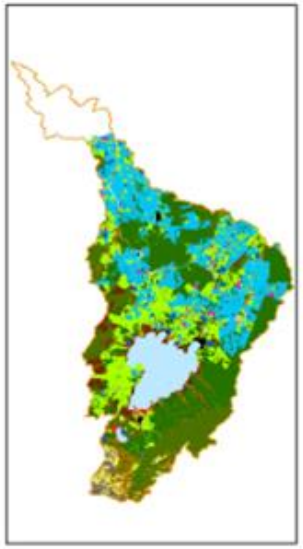
Arapuni



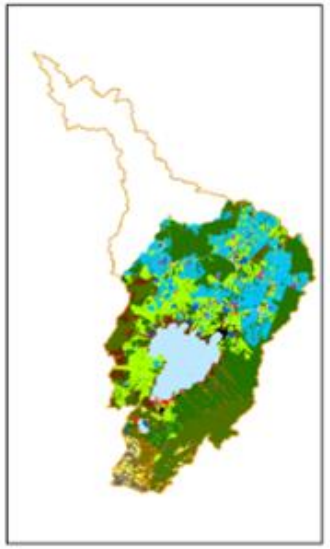
Aratiata



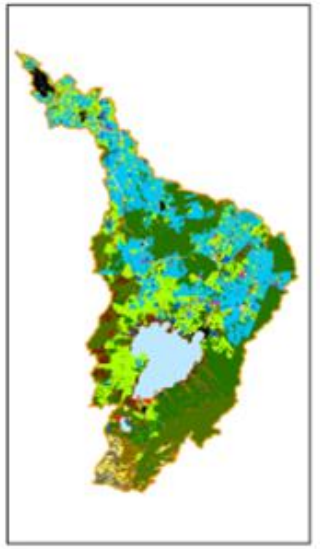
Atiamuri



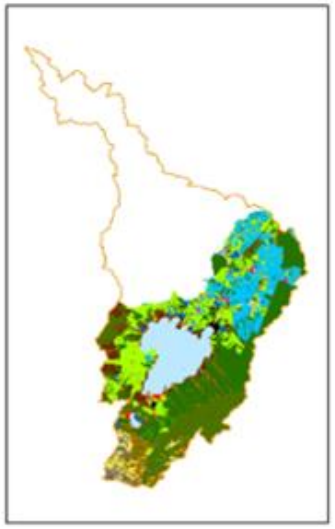
Karapiro



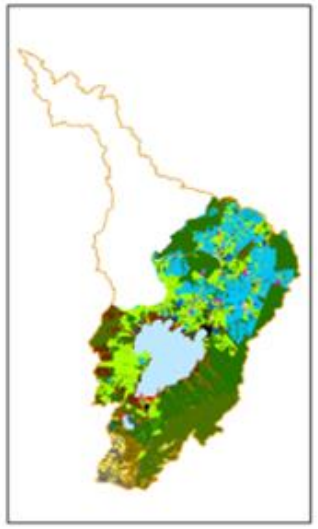
Maraetai 1&2



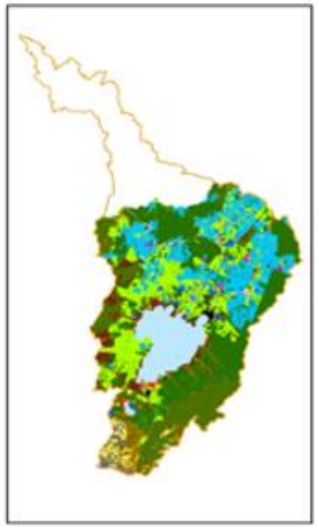
Ngaruawahia



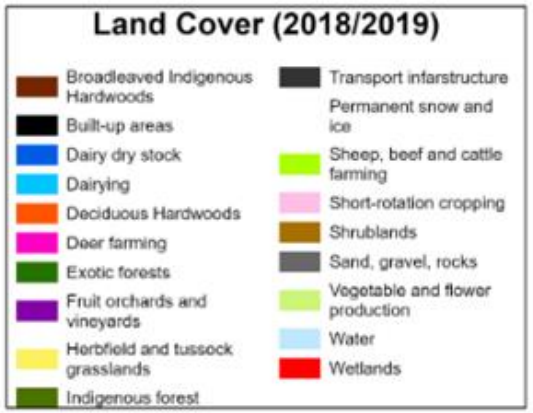
Ohakuri



Whakamaru

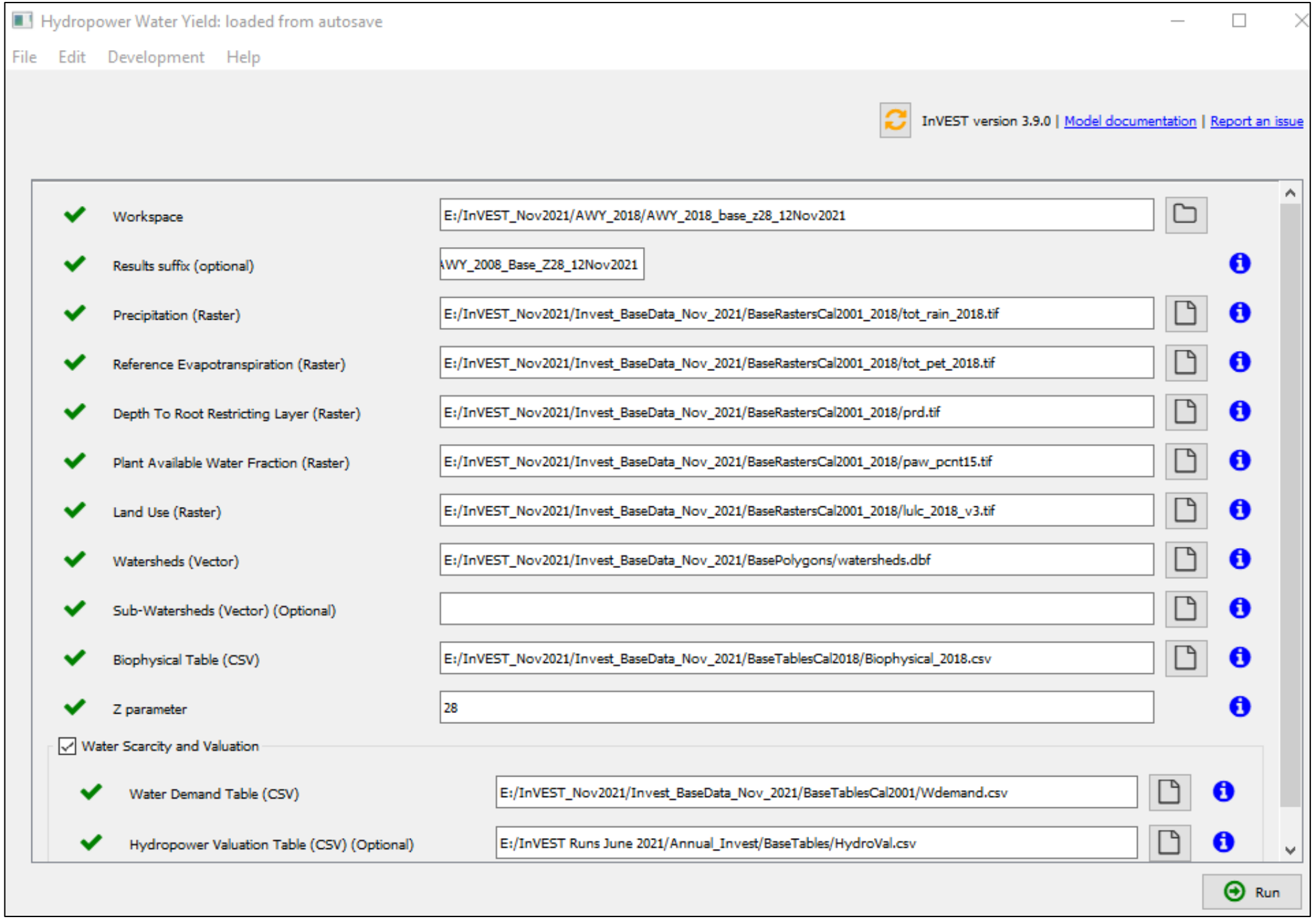


Waipapa

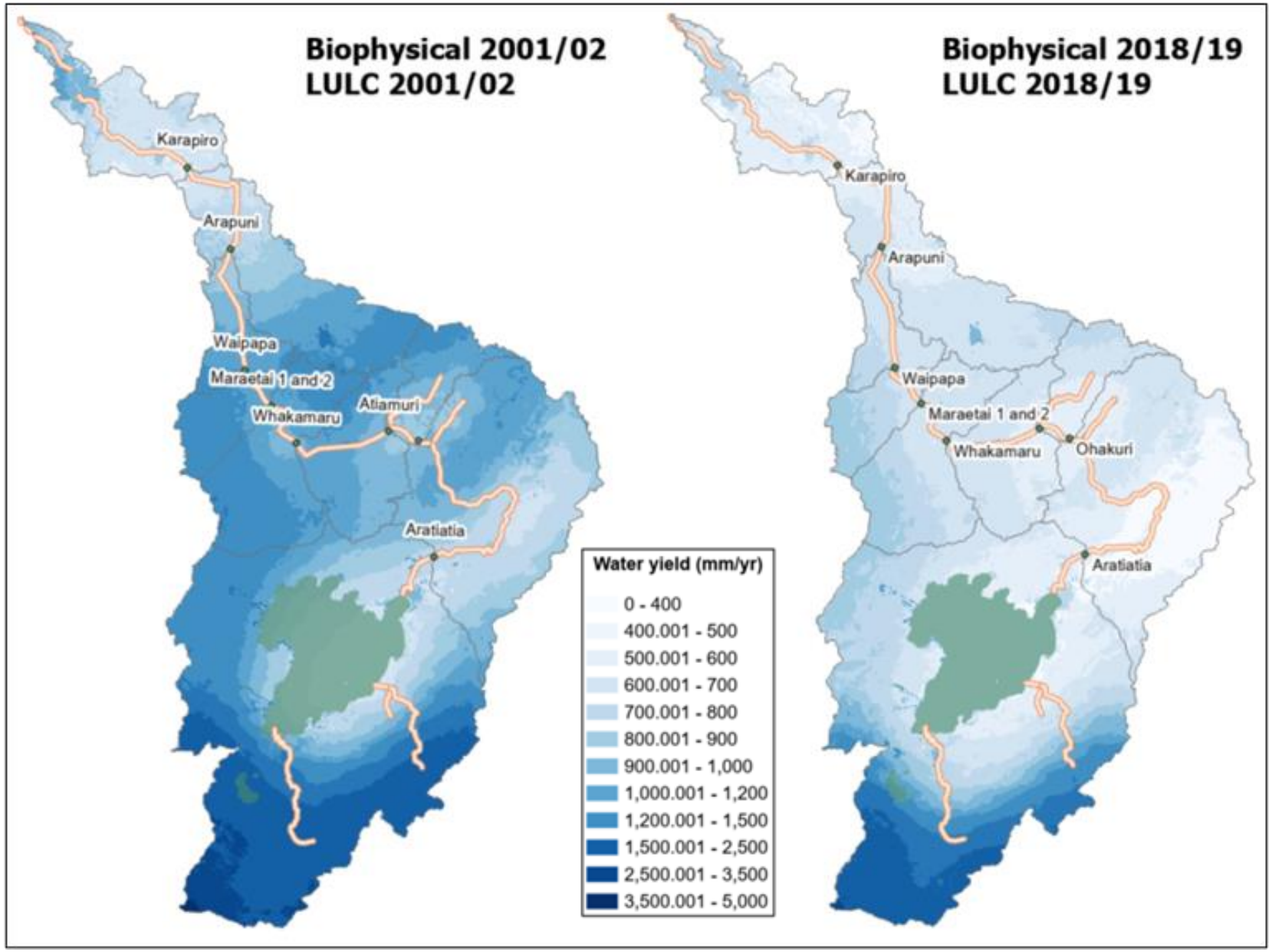


Sub-catchment	Area (ha)
Aratiatia	356,648
Ohakuri	505,533
Ātiamuri	533,309
Whakamaru	584,375
Maraetai 1 & 2	649,545
Waipapa	675,176
Arapuni	700,636
Karapiro	781,115
Full catchment	**838,505**

InVEST Water Yield model interface



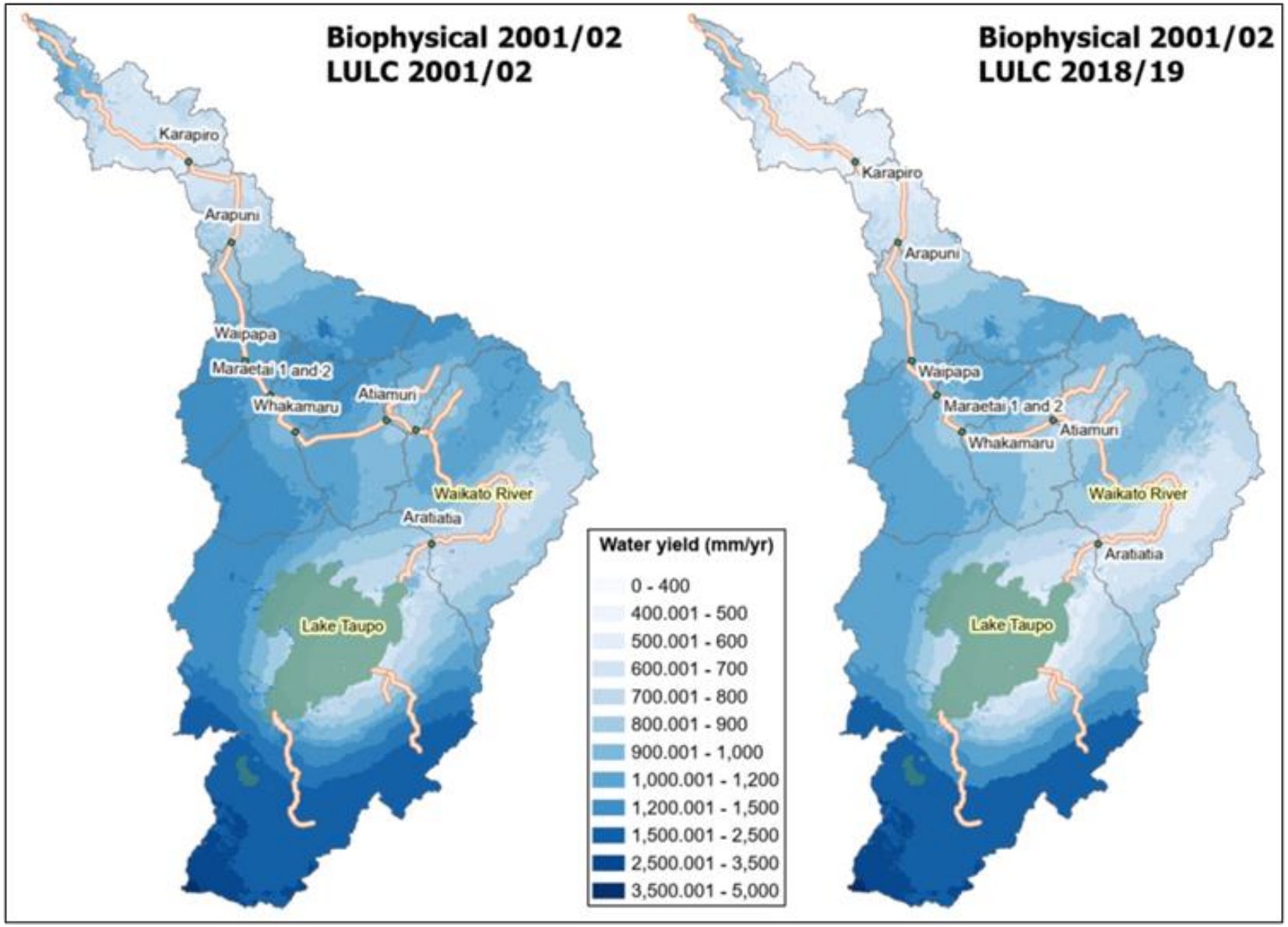
Annual Water Yield - 2001/02 & 2018/19



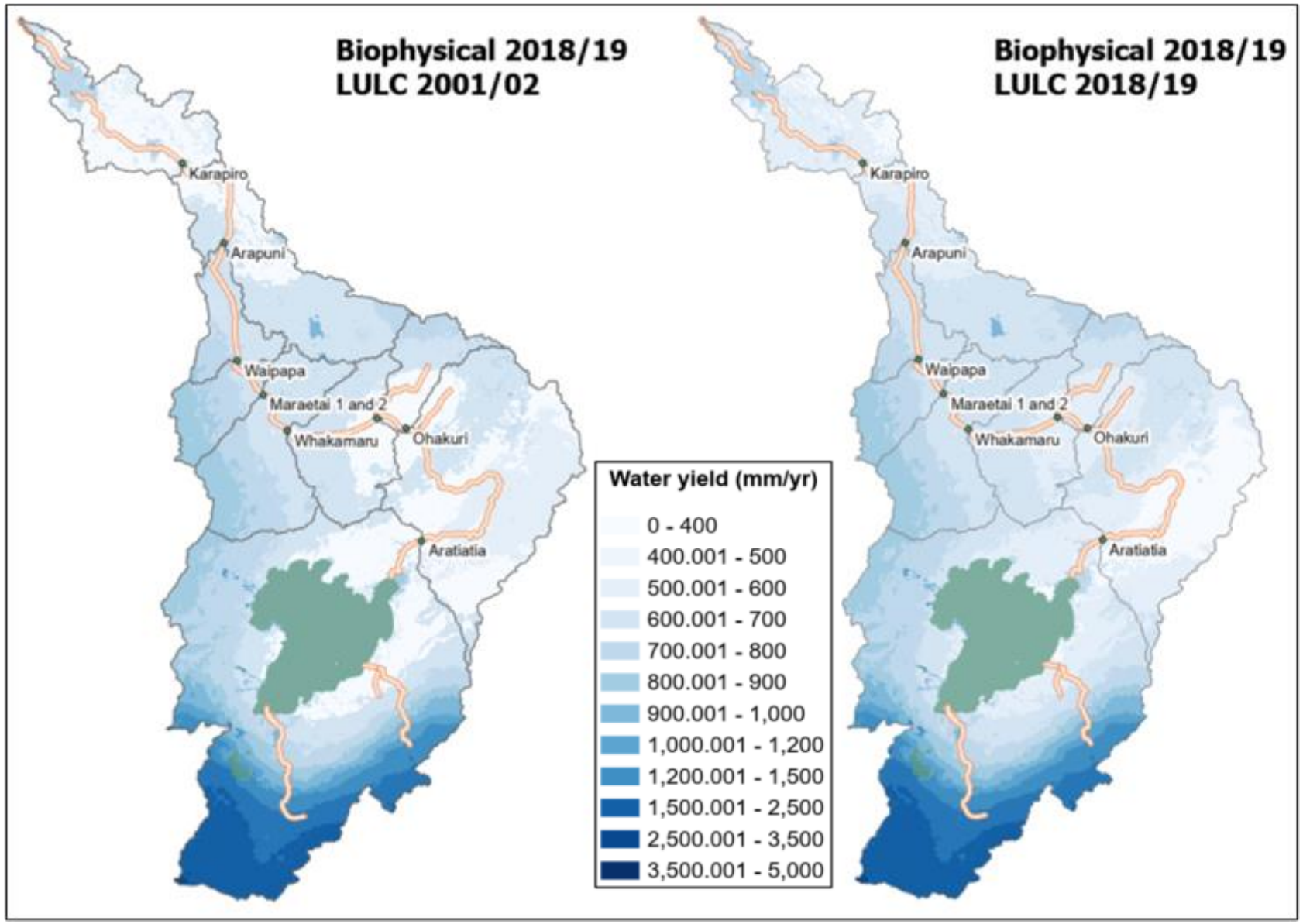
InVEST Water Yield model outputs
(% change - 2001/02 & 2018/19)

Catchment	Area (ha)	Rainfall	Water yield	Water consumption	Hydropower
Karapiro	781,115	-24%	-40%	55%	-52%
Arapuni	700,636	-25%	-40%	58%	-50%
Waipapa	675,176	-25%	-40%	59%	-50%
Maraetai 1 and 2	649,545	-25%	-40%	59%	-50%
Whakamaru	584,375	-25%	-40%	58%	-49%
Atiamuri	533,309	-25%	-40%	54%	-48%
Ohakuri	505,533	-25%	-40%	53%	-47%
Aratiatia	356,648	-25%	-39%	4%	-41%
Average change		***-25%***	***-40%***	***50%***	***-48%***

Annual water yield using biophysical and rainfall data in **2001/02** with LULC classes for 2001/02 and 2018/19



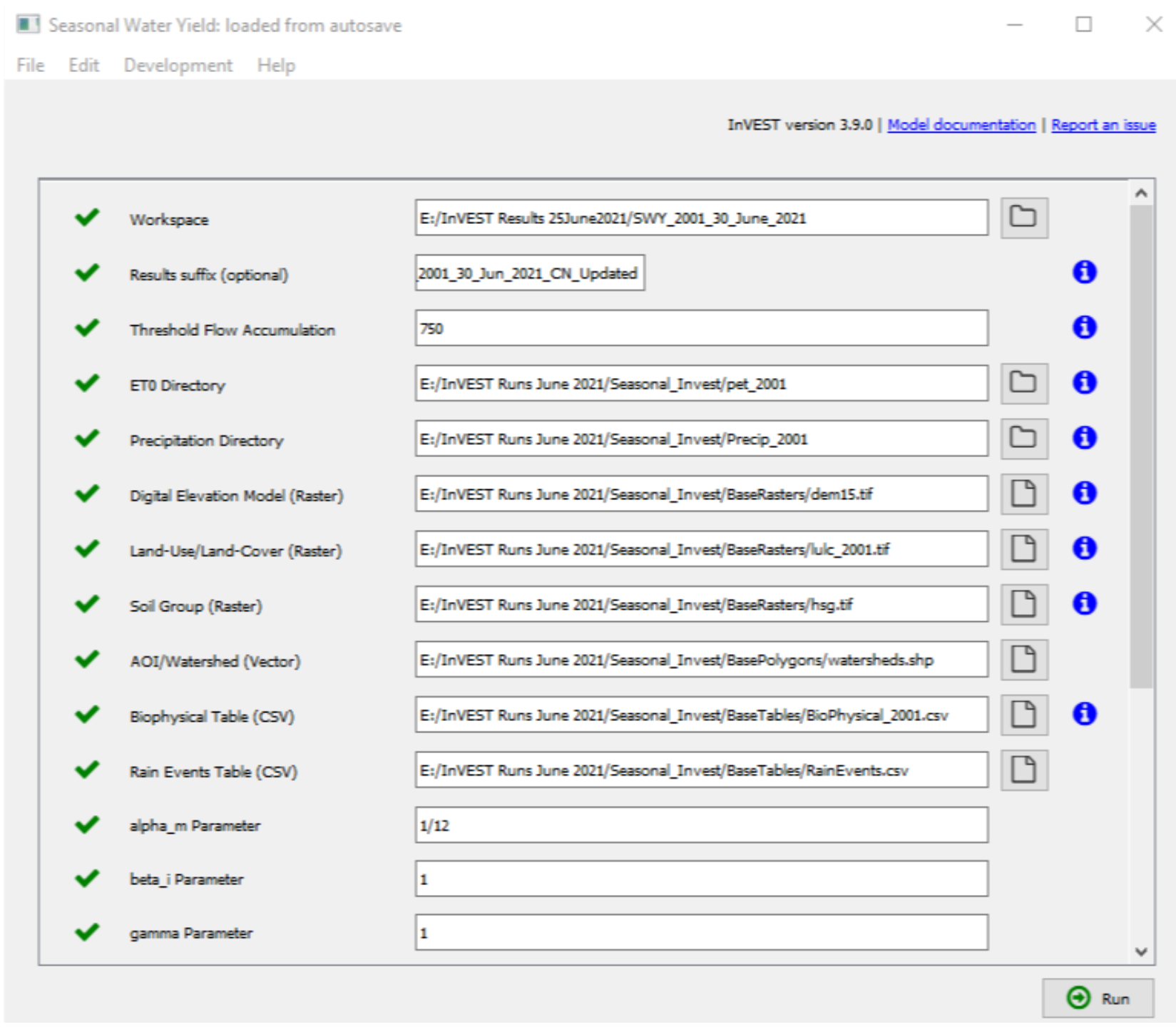
Annual water yield using biophysical and rainfall data in **2018/19** with LULC classes for 2001/02 and 2018/19



% change in water yield and hydropower generation

Sub-catchment	Area (ha)	Water Yield		Hydropower generation	
		2001/02	*2018/19*	*2001/02*	*2018/19*
Aratiatia	356,648	-0.01%	-0.08%	-1.9%	-3.3%
Ohakuri	505,533	-0.08%	-0.07%	-4.7%	-8.3%
Ātiamuri	533,309	-0.09%	-0.07%	-5.0%	-8.8%
Whakamaru	584,375	-0.10%	-0.06%	-5.3%	-9.4%
Maraetai 1 & 2	649,545	-0.11%	-0.06%	-5.4%	-9.7%
Waipapa	675,176	-0.11%	-0.07%	-5.3%	-9.5%
Arapuni	700,636	-0.11%	-0.07%	-5.5%	-9.8%
Karapiro	781,115	-0.13%	-0.06%	-6.1%	-11.1%
Full catchment	**838,505**	**-0.09%**	**-0.01%**		

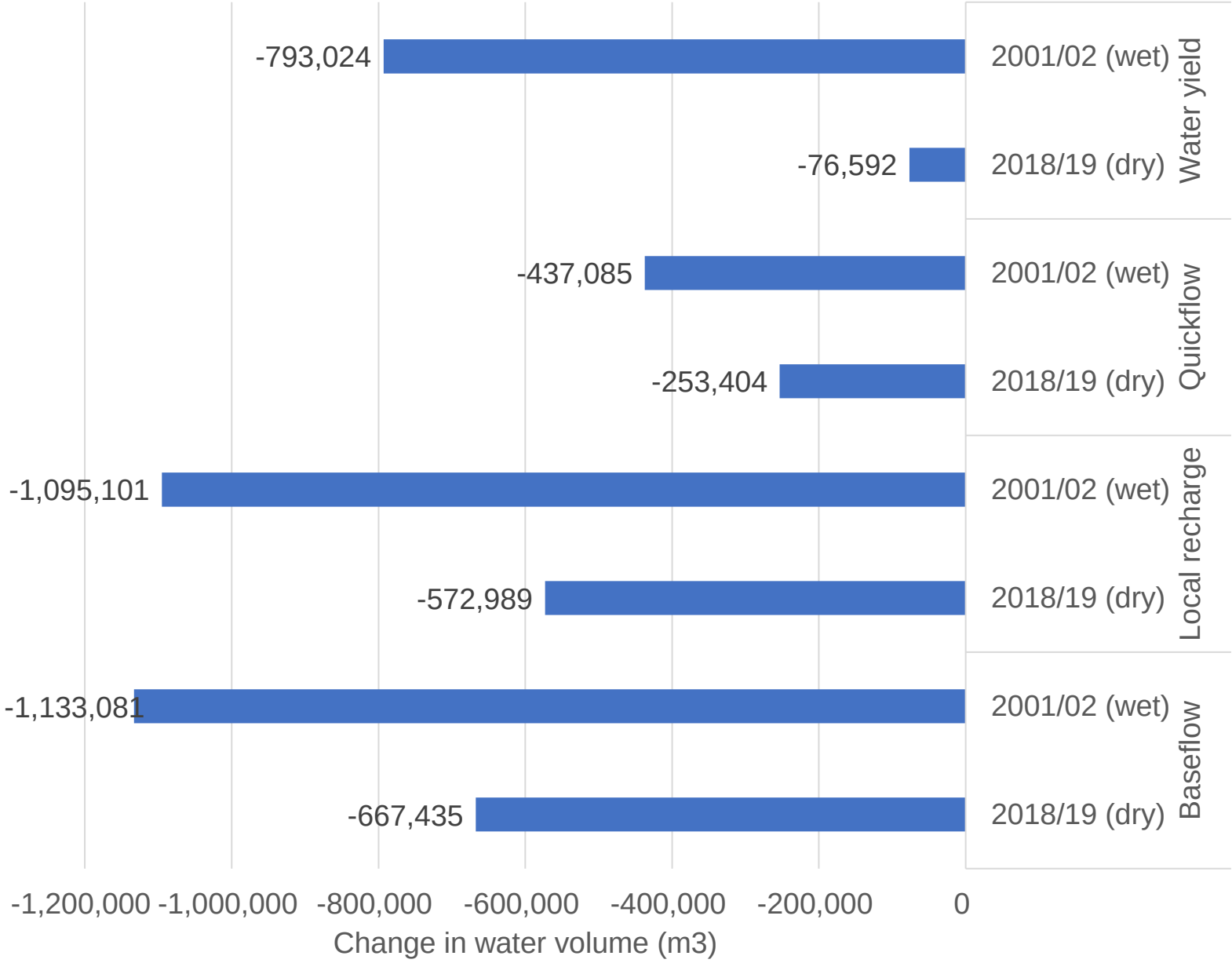
InVEST Seasonal Water Yield (SWY) model interface



SWY - % change in quickflow and local recharge

Sub-catchment	Area (ha)	Quickflow		Local recharge	
		2001/02	*2018/19*	*2001/02*	*2018/19*
Aratiatia	356,648	-0.03	0.01	0.09	0.07
Ohakuri	505,533	-0.10	-0.05	-0.11	-0.12
Ātiamuri	533,309	-0.16	-0.10	-0.11	-0.12
Whakamaru	584,375	-0.23	-0.16	-0.12	-0.12
Maraetai 1 & 2	649,545	-0.25	-0.18	-0.14	-0.15
Waipapa	675,176	-0.26	-0.19	-0.14	-0.14
Arapuni	700,636	-0.26	-0.19	-0.15	-0.16
Karapiro	781,115	-0.29	-0.22	-0.20	-0.21
Full catchment	**838,505**	**-0.30**	**-0.24**	**-0.15**	**-0.14**

Change in water flow regulation ecosystem services due to LULC change



Pilot ecosystem extent account - 2001/02 and 2018/19

		Ecosystem Type (Land Use/Land Cover Class)																		
		Broadleaved indigenous hardwoods	Built-up areas	Dairy dry stock	Dairying	Deciduous hardwoods	Deer farming	Exotic forests	Fruit orchards and vineyards	Herbfield and tussock grasslands	Indigenous forest	Sand, gravel, rocks	Transport infrastructure	Sheep, beef and cattle farming	Short-rotation cropping	Shrublands	Permanent snow and ice	Vegetable and flower production	Water	Wetlands	Total
Area (ha)	2001/02	29,830.7	11,671.8	14,574.9	97,542.5	2,045.1	11,911.7	247,609.3	680.5	11,639.5	103,282.0	662.7	102.8	190,034.1	1,952.3	34,410.0	7,794.2	456.8	69,230.7	3,072.7	838,504.5
	2018/19	29,362.8	13,592.1	15,578.2	179,206.2	1,747.6	3,637.8	201,852.0	847.7	11,639.6	101,556.7	614.0	102.8	162,470.9	1,921.5	33,824.0	7,788.6	800.6	69,193.9	2,767.4	838,504.5
	Area change (2018/19 less 2001/02)	-467.9	1,920.4	1,003.3	81,663.7	-297.5	-8,273.9	-45,757.4	167.2	0.0	-1,725.4	-48.7	0.0	-27,563.2	-30.8	-586.0	-5.6	343.7	-36.8	-305.2	
% change [(2018/19 less 2001/02) ÷ (2001/02)]		-1.6	16.5	6.9	83.7	-14.5	-69.5	-18.5	24.6	0.0	-1.7	-7.3	0.0	-14.5	-1.6	-1.7	-0.1	75.2	-0.1	-9.9	

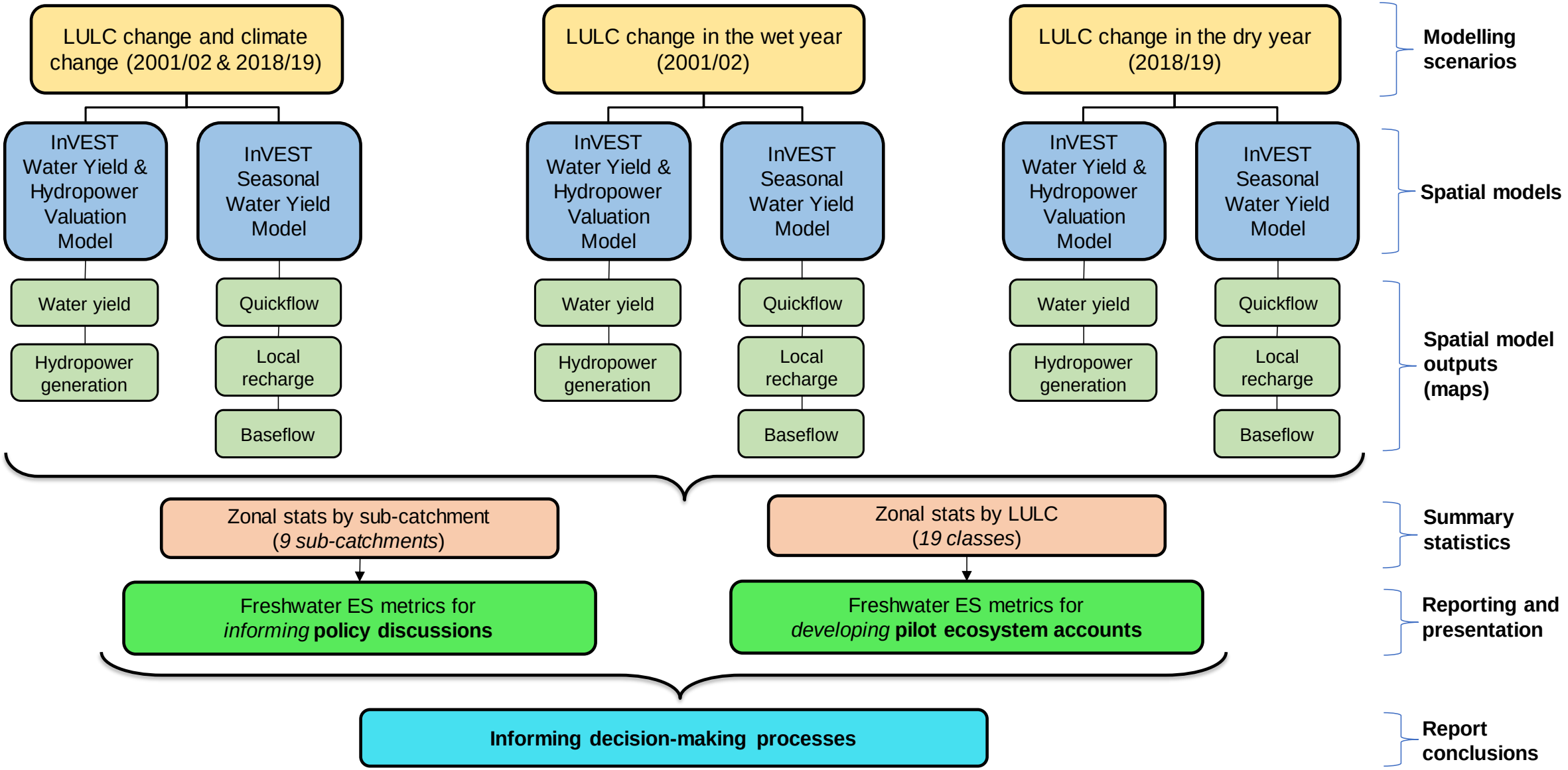
Pilot ecosystem capacity account - 2001/02 and 2018/19

		Ecosystem Type (Land Use/Land Cover (LULC) Class)																		
		Broadleaved indigenous hardwoods	Built-up areas	Dairy dry stock	Dairying	Deciduous hardwoods	Deer farming	Exotic forests	Fruit orchards and vineyards	Herbfield and tussock grasslands	Indigenous forest	Sand, gravel, rocks	Transport infrastructure	Sheep, beef and cattle farming	Short-rotation cropping	Shrublands	Permanent snow and ice	Vegetable and flower production	Water	Wetlands	Total
Water yield ('000 m3/year)	Biophysical, climate & LULC 2001/02	30,042	10,895	10,506	75,633	1,792	9,949	229,839	380	29,861	158,010	867	463	170,230	1,320	57,831	20,485	296	33,446	3,354	845,199
	Biophysical, climate & LULC 2018/19	17,817	9,179	8,243	87,975	946	1,763	111,359	330	20,900	95,965	543	320	91,289	935	37,086	13,637	421	12,780	1,823	513,309
	Change in water yield (2018/19 less 2001/02)	-12,225	-1,717	-2,263	12,342	-846	-8,186	-118,480	-50	-8,961	-62,045	-324	-142	-78,941	-384	-20,745	-6,849	124	-20,666	-1,531	-331,890
	% change = [Change ÷ (2001/02)] X 100%	-40.69	-15.76	-21.54	16.32	-47.20	-82.28	-51.55	-13.10	-30.01	-39.27	-37.42	-30.80	-46.37	-29.12	-35.87	-33.43	41.96	-61.79	-45.64	-39.27
Quickflow ('000 m3/year)	Biophysical, climate & LULC 2001/02	2,215	1,225	783	5,960	842	556	11,932	37	7,076	7,297	213	412	12,632	206	5,488	8,573	47	74,197	3,874	143,564
	Biophysical, climate & LULC 2018/19	1,386	967	689	7,996	542	117	7,021	36	3,542	4,980	99	278	7,738	132	3,423	4,802	66	60,149	2,420	106,381
	Change in quickflow (2018/19 less 2001/02)	-829	-258	-95	2,036	-300	-439	-4,911	-1	-3,534	-2,317	-113	-134	-4,894	-74	-2,065	-3,771	19	-14,048	-1,455	-37,183
	% change = [Change ÷ (2001/02)] X 100%	-37.44	-21.03	-12.11	34.15	-35.60	-78.96	-41.16	-2.81	-49.94	-31.76	-53.36	-32.52	-38.74	-35.92	-37.63	-43.99	39.23	-18.93	-37.55	-25.90
Local recharge ('000 m3/year)	Biophysical, climate & LULC 2001/02	27,276	9,661	9,038	65,304	812	8,949	214,856	320	21,568	149,808	654	51	150,119	949	51,515	11,924	188	-7,165	-1,283	714,546
	Biophysical, climate & LULC 2018/19	15,703	8,176	6,827	71,400	262	1,489	100,103	256	15,817	89,662	442	42	76,526	630	32,605	8,834	255	-5,689	-1,276	422,061
	Change in local recharge (2018/19 less 2001/02)	-11,574	-1,485	-2,211	6,095	-551	-7,461	-114,754	-65	-5,751	-60,145	-212	-9	-73,593	-319	-18,910	-3,090	67	1,476	7	-292,485
	% change = [Change ÷ (2001/02)] X 100%	-42.43	-15.37	-24.46	9.33	-67.80	-83.37	-53.41	-20.20	-26.67	-40.15	-32.46	-16.81	-49.02	-33.64	-36.71	-25.92	35.86	-20.60	-0.52	-40.93
Baseflow ('000 m3/year)	Biophysical, climate & LULC 2001/02	27,968	9,815	9,332	67,644	1,130	9,138	218,907	337	21,690	151,354	661	51	153,875	1,011	52,630	12,089	200	19	0	737,851
	Biophysical, climate & LULC 2018/19	16,350	8,358	7,119	75,510	535	1,539	103,609	276	15,956	91,343	449	42	79,883	681	33,763	9,030	275	14	0	444,732
	Change in baseflow (2018/19 less 2001/02)	-11,619	-1,457	-2,213	7,866	-595	-7,599	-115,298	-62	-5,733	-60,011	-213	-9	-73,992	-330	-18,867	-3,058	75	-5	0	-293,119
	% change = [Change ÷ (2001/02)] X 100%	-41.54	-14.85	-23.71	11.63	-52.68	-83.16	-52.67	-18.28	-26.43	-39.65	-32.15	-16.81	-48.09	-32.66	-35.85	-25.30	37.66	-26.53	4.36	-39.73

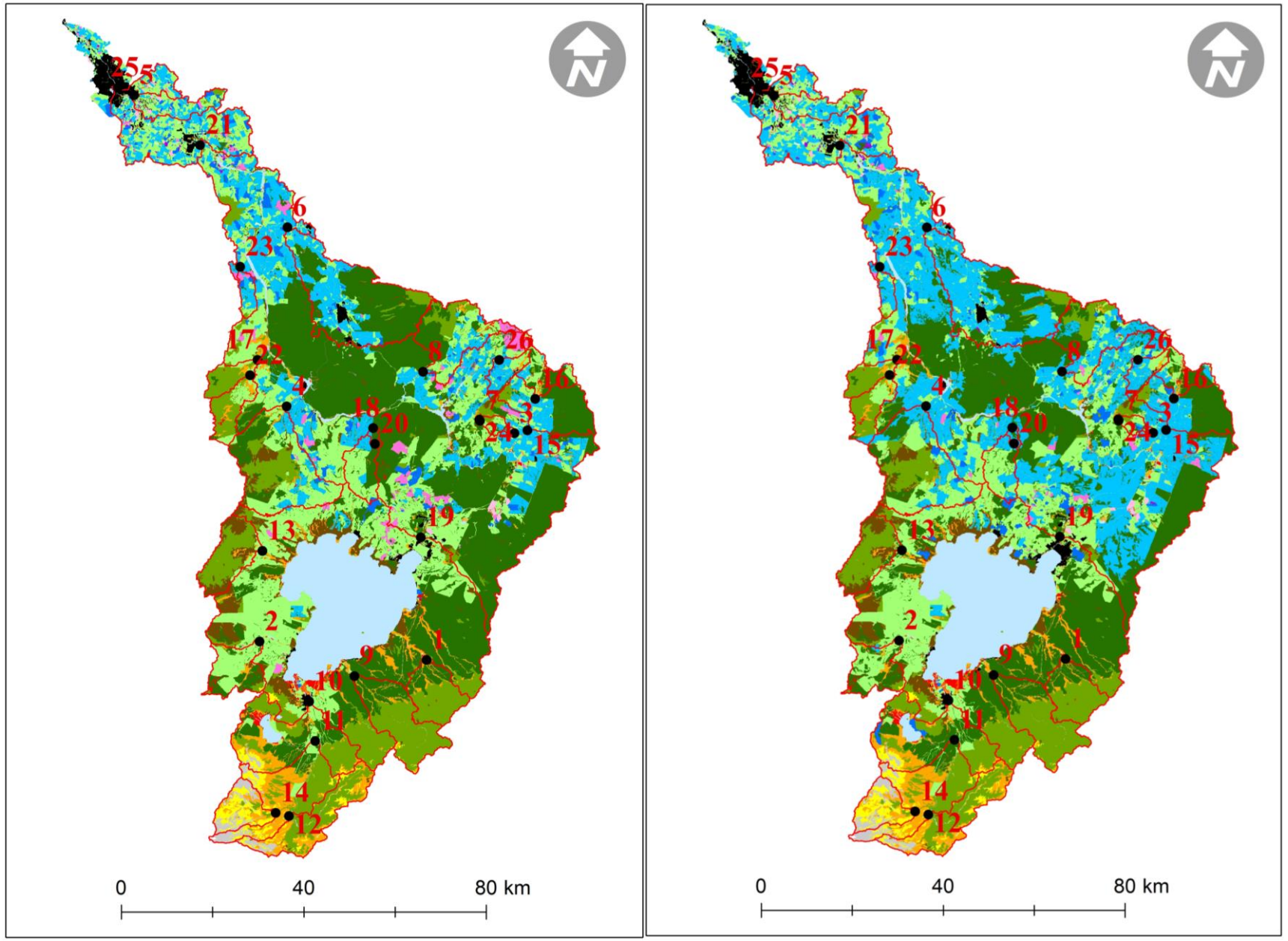
Discussion and where to next

- First NZ application InVEST: Water Yield and Seasonal Water Yield models
- Sub-catchment level analysis evaluated LULC impacts on water flow ES and hydropower generation
- Analysis by LULC class helped create pilot ecosystem accounts under three impact scenarios:
  - LULC and climate change between 2001/02 and 2018/19
  - LULC change within 2001/02 (wet)
  - LULC change within 2018/19 (dry)
- Developed & applied a framework to quantify LULC impacts on 5 water ES
- Just started to calibration process - compare measured annual water flow (mm/year) with InVEST modelled flow (mm/year)

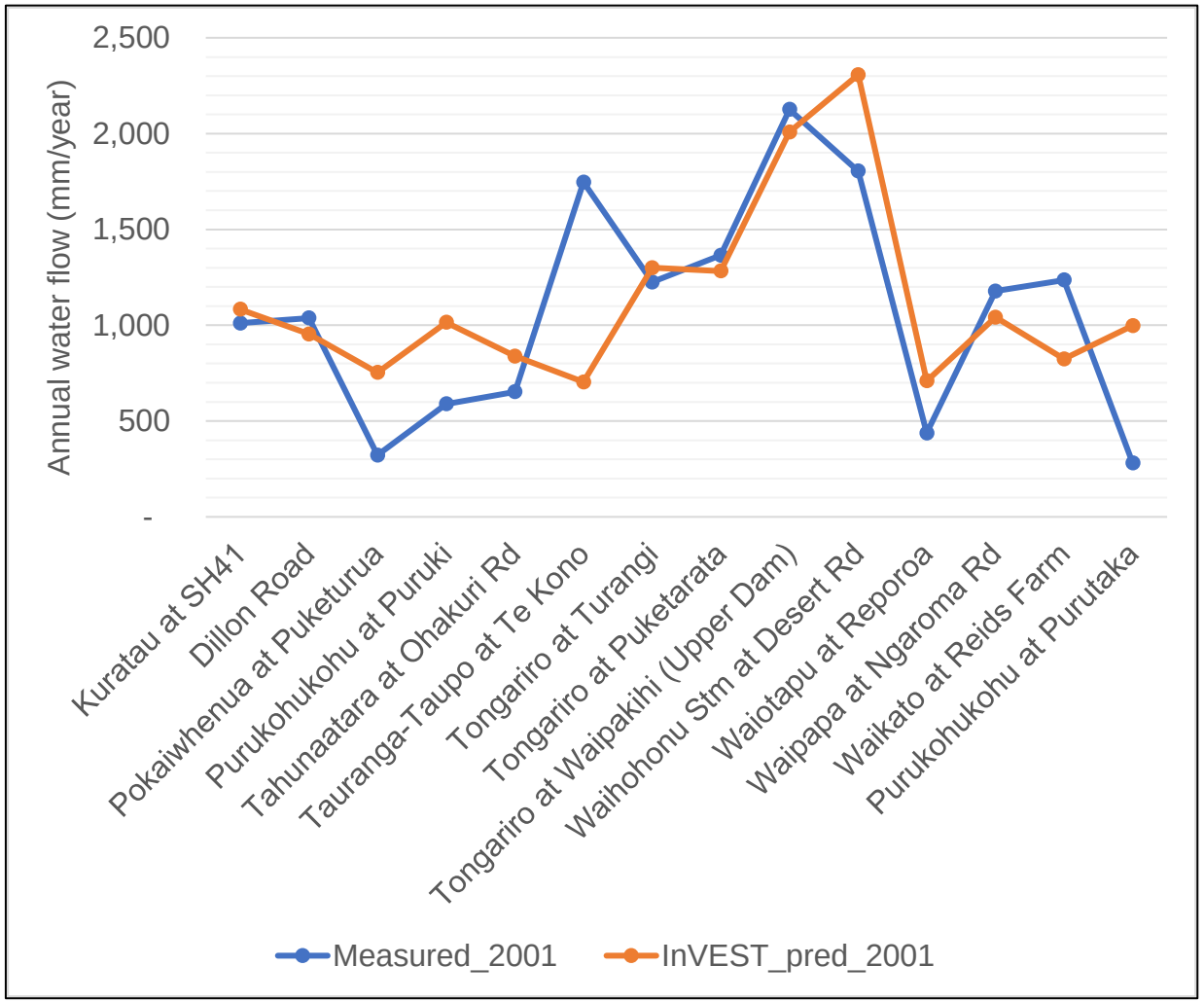
Freshwater ecosystem services assessment framework

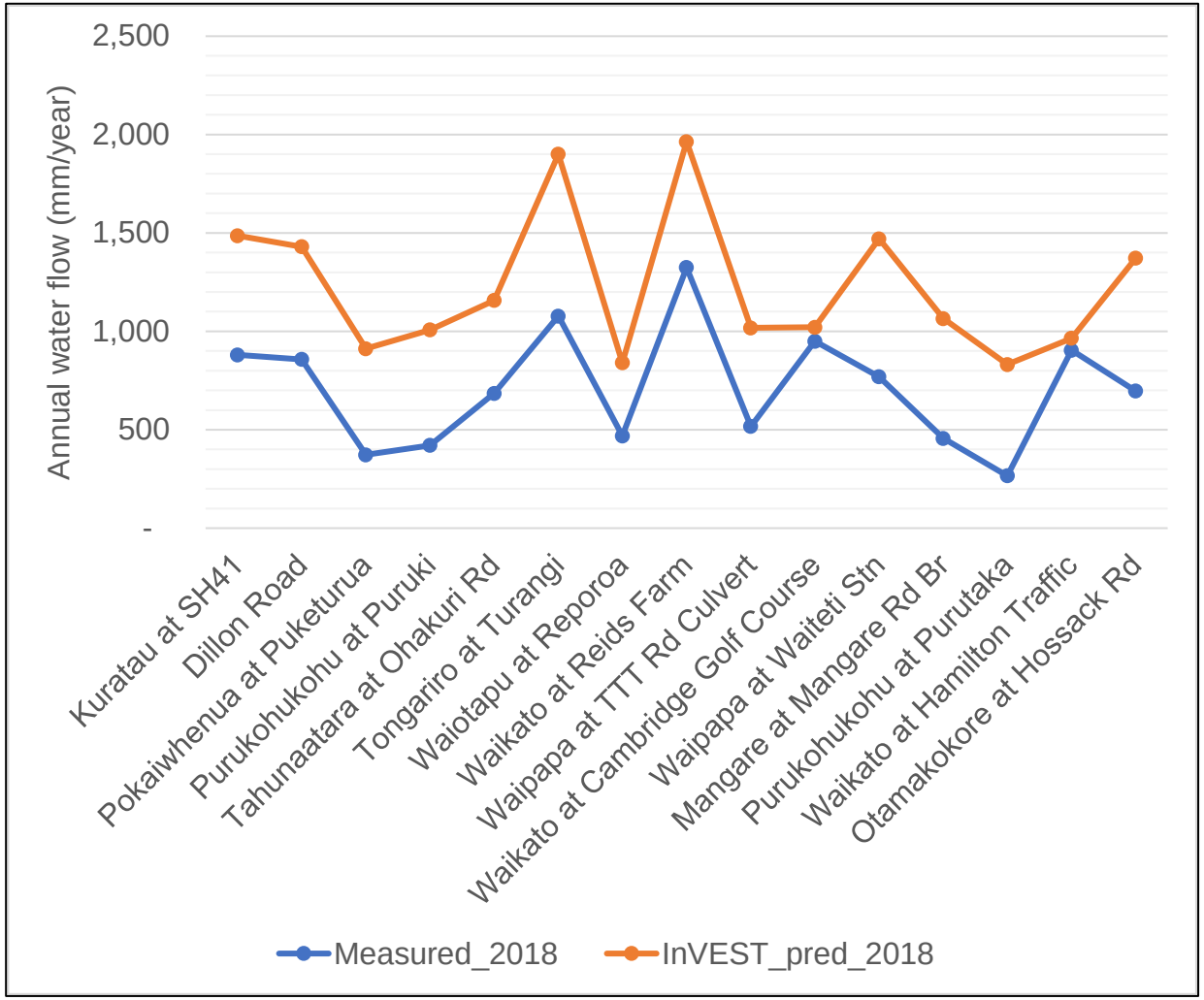


Annual water yield candidate calibration cacthments

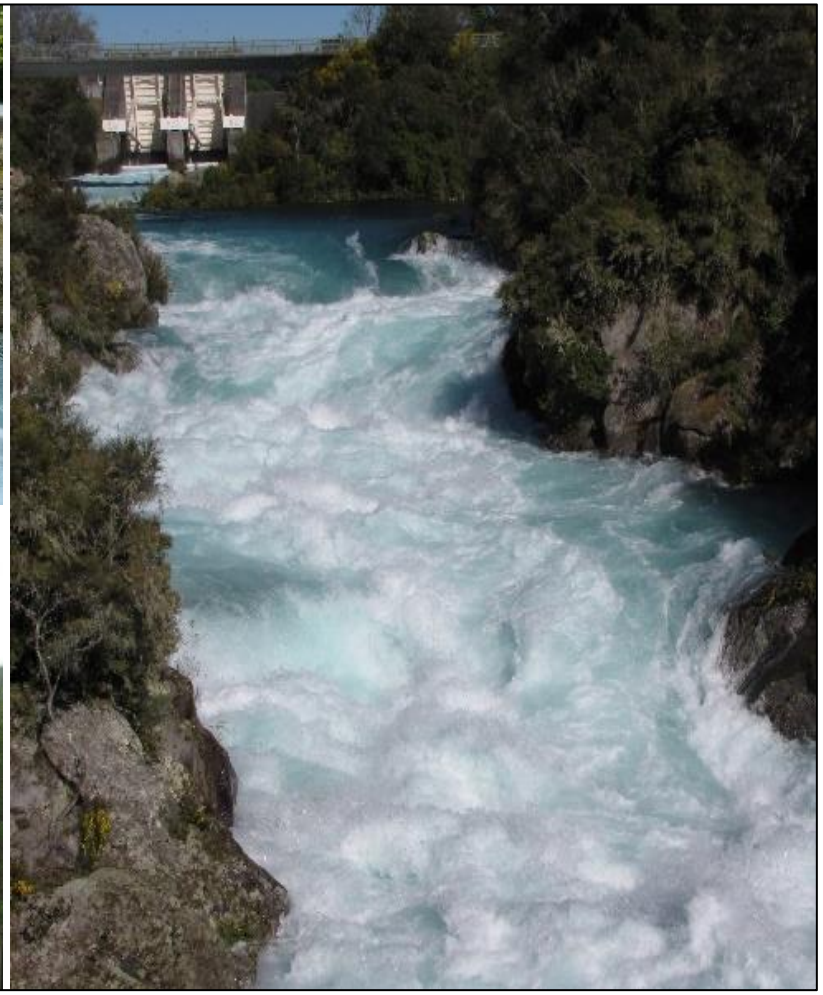


Measured versus InVEST predicted water flow (mm/year)





Thank you!



Richard T. Yao, PhD
richard.yao@scionresearch.com
https://www.scionresearch.com/