September 10, 2025

The Honourable Randene Neill
Minister of Water, Land and Resource Stewardship
By email

Dear Minister Neill

Groundwater Concerns – Fanny Bay

Attached please find a briefing note to bring you up to speed with respect to the groundwater concerns of our Fanny Bay community.

In brief, two multinational companies – Natural Glacial Waters and Cermaq - have applied to your Ministry for Existing Use Groundwater licenses to continue to pump substantial volumes of water from our fragile aquifers.

It is our understanding that neither application has been as yet reviewed. We hope the attached will persuade you to commit to full public hearings when these applications are under review to allow our community to present and examine evidence.

Kind regards

Wendy Holm (and Leah Weinberg)
Fanny Bay, BC V0R1W0

cc: Daniel Arbour, Director,
Comox Valley Regional District Baynes Sound / Denman & Hornby Islands

Briefing Note – Groundwater Resources in Fanny Bay[1]
September 3, 2025

SUMMARY:

Fanny Bay's aquifers are amongst the most fragile and threatened on Vancouver Island. Many private wells in our community are drying up. This summer, starting in July, springs that feed our spawning streams dried up, many ponds were almost empty, and some families had no water at all. Meanwhile, two private investors have applied to the province to continue to divert large volumes of groundwater from our aquifers. It is our understanding that these license applications have not yet been considered. The Fanny Bay Groundwater Collective seeks government's commitment to 1) a full and transparent public hearing process as part of any consideration of commercial groundwater licensing for these two entities and 2) the timely imposition of temporary restrictions on historic diversion volumes in light of severe drought impacting our community.

INTRODUCTION:

Groundwater came under provincial regulation in 2016 with the passage of the Water Sustainability Act (BC) (the Act). Companies who extracted groundwater for commercial purposes prior to the 2016 Act are considered transitioning groundwater users: required to apply for a provincial groundwater license by March 1, 2022 but authorized to continue to divert groundwater based on their historic use until their license application is processed. There are a number of transitioning groundwater users in our community.[2] Fisheries and Oceans Canada draws groundwater for their Rosewall Creek Research Hatchery. Two multinational companies divert substantial volumes of water from the community aquifers: CERMAQ to produce eggs for their coastal fish farms and Natural Glacial Waters BC to export in 500 ml bottles.

The queue for groundwater licenses is, apparently, a long one. It is our understanding, based on discussions with the Existing Use Groundwater Team (EUGT), Water Management Branch, BC Ministry of Water, Land and Resource Stewardship (WLRS), that the groundwater license applications for both CERMAQ and Natural Glacial Waters BC have not yet been reviewed and, as the date of this document, are still pending.

We request The Hon. Randene Neill, BC Minister of Water, Land and Resource Stewardship responsible for groundwater oversight and licensing under the Water Sustainability Act, to commit to holding public hearings in our community as part of the groundwater license review process to be informed by the knowledge of area residents and their experts as to the impact these withdrawals are having on the sustainability of our groundwater aquifer. In the meantime, in this period of drought, we also ask the Minister to take measures available to her under the Act to constrain the commercial diversion of groundwater.

A recent study on global groundwater depletion[3] (for full text see Appendix E) had this to say:

> *"At present, overpumping groundwater is the largest contributor to rates of TWS [terrestrial water storage] decline in drying regions, significantly amplifying the impacts of increasing temperature, aridification, and extreme drought events. However, groundwater depletion is most directly affected by, and can also be arrested by, water management decisions.... In many places where groundwater is being depleted, it will not be replenished on human timescales. The disappearance of groundwater from the world's aquifers is a critical, emerging threat to humanity and presents cascading risks that are rarely incorporated in environmental policy, management, and governance. It is an intergenerational resource that is being poorly managed, if managed at all, by recent generations, at tremendous and exceptionally undervalued cost to future generations. Protecting the world's groundwater supply is paramount in a warming world and on continents that we now know are drying."*

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[1] Prepared by Wendy Holm Leah Weinberg to brief Daniel Arbour, CVRD & Hon. Randene Neill, Min Water, Land Resource Stewardship.
[2] The smallest, Diamond Springs Water Bottling Cooperative, suspended operations for two years pending research into aquifer capacity and the outcome of a community dialogue regarding the potential value of a community well. diamondspringswaterbottling.coop
[3] Unprecedented continental drying, shrinking freshwater availability, and increasing land contributions to sea level rise. July 25, 2025. Hrishikesh A. Chandanpurkar, James S. Famiglietti, Kaushik Gopalan, David N. Wiese, Yoshihide Wada, Kaoru Kakinuma, John T. Reager, Fan Zhang. Science Advances Research Article Climatology. https://www.science.org/doi/10.1126/sciadv.adx0298

CERMAQ

CERMAQ (formerly United Hatcheries), is a subsidiary of Mitsubishi and is located on White Duck Road. It is withdrawing groundwater for the production of Atlantic salmon eggs to supply their fish farms. CERMAQ has three wells with a combined capacity of close to 1,500 gallons per minute.

Well #	Date Registered	Plate ID	Depth (ft)	Capacity (US gpm)
122976	Mar 1995	44495	90	650-750[4]
128344	Jul 2023	68057	75	300
129614	Feb 2024	69051	73	500

The volume of water currently used by CERMAQ is unknown[5]. Its potential impact on area wells is documented in an October 18, 1991 internal memo from Rodney Zimmerman, Geological Engineer to A.P. Kohut, Acting Head, Groundwater Section, Water Management Division, BC[2] (see Appendix A). In his assessment of the impact of the hatchery's use on aquifer stakeholders, Zimmerman notes:

> *Pumping… is interfering to some degree with some of the neighbouring wells and ponds… [extent and magnitude… not known] … …depending on pumping levels… saline water may advance further into the freshwater aquifer due to increased groundwater withdrawals… [this] may affect flow in [Wilfred] creek… and may be a concern to the marsh areas around Little Bay…*

It is not known whether Zimmerman's recommendations to measure and mitigate excessive interference on neighbouring wells and ponds were actioned. Beaufort Watershed Stewards has undertaken significant work to measure changes in the watershed to protect the ecosystem, but serious questions remain concerning the impact CERMAQ's groundwater diversion is having on aquifer sustainability and the productivity and sustainability of local residential water wells.

<u>Questions Regarding CERMAQ:</u>

1. Where in the queue is CERMAQ's groundwater license application and when is it likely to be considered by the Water Management Branch?
2. How much groundwater is CERMAQ diverting per year? Has this increased over time? What are the maximum pumping rates per day?
3. Were the 1991 recommendations of Geological Engineer Rodney Zimmerman acted on? (For example, is CERMAQ undertaking regular pump testing to include a distance drawdown relationship and any proposed strategies to mitigate the effects of any excessive well interference on neighboring wells and ponds?)
4. What percentage of groundwater/effluent does CEMAQ recycle? How is this accomplished? Where is it discharged (surface or groundwater)? How is it monitored and by whom?

NATURAL GLACIAL WATERS

Natural Glacial Waters operates a bottling plant on Berray Road. According to a November 19, 2024 letter to Dave Weaver, Beaufort Water Stewards from Lori Halls, D.M., Water, Land and Resource Stewardship (Appendix B), Natural Glacial Waters has been "diverting 1,892,160 cubic metres per year from the aquifer since July 1, 1998." This is the equivalent of 416,217,013 Imperial gallons (half a billion US gallons) of groundwater a year (5.2 million litres a day, the residential equivalent of over 28,961[6] persons/day). The water is sold in 500 ml plastic bottles under the label ICEFIELD to clients in Japan, Taiwan and Mainland China. Apparently, the plant has been shut down for some time (perhaps several years), during which time it was vandalized (stripped of copper fittings). We understand repair work has been completed, and they expected to resume bottling operations in August 2025.[7]

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[4] Written in response to letter of concern regarding well interference complaints from Jack Turner, Director, Electoral District "A", Regional District of Comox-Strathcona.

[5] CEMAQ claims to recycle 80% of its water. The process they use to recycle groundwater is not known.

[6] Based on City of Nanaimo 2024 Annual Water Quality Report 2024 of average residential only consumption: 179 litres/person/day

[7] Personal communication with an on-site employee, July 25, 2025

Questions Regarding Natural Glacial Waters:

1. Where in the queue is Natural Glacial Waters' groundwater license application and when is it likely to be considered by the Water Management Branch?
2. How much groundwater is Natural Glacial Waters diverting per year? Has this increased over time? What are the maximum pumping rates per day?
3. Are there any seasonal or ecological constraints, including low-flow limitations attached to Natural Glacial Water's license or transitional use permit?
4. Does the license or transitional use permit require monitoring plans, potential aquifer impact mitigation, and submission of well records so drawdown or contamination risk can be evaluated?
5. What is the reason Natural Glacial Waters recently shut down? For how long were they shut down? What impact does this have on their license and/or transitional use permit?

FRAGILITY OF FANNY BAY AQUIFERS AND SALINIZATION RISK

Fanny Bay residents depend on a groundwater resource that is already highly vulnerable. Appendix C, produced by the Vancouver Island Water Resources Vulnerability Mapping Project, illustrates the risk our aquifers face from contamination. As Zimmerman (1991) notes, when groundwater is withdrawn from an aquifer at a faster rate than it can recharge itself, hydrostatic pressure is lost. In our coastal communities, this can allow saline seawater to move inland, contaminating local aquifers and wells. Commercial extraction exacerbates this risk.

BC GOVERNMENT APPROVAL OF GROUNDWATER LICENSES

The Hon. Randene Neill, BC Minister of Water, Land and Resource Stewardship and MLA for Powell River–Sunshine Coast is the BC Minister responsible for groundwater oversight - including licensing - under the Water Sustainability Act. In Minister Neill's January 16, 2025 Mandate letter, Premier David Eby identifies her responsibility to:

> *Work with communities affected by drought, or expected to face water shortages, to support community-based priority setting between industrial, agricultural, residential, and environmental uses for water. Ensure better coordination between water regulators and local communities in advance of drought to support effective response during an emergency.*
>
> *Use this mandate letter to guide your work, and do not be afraid to challenge assumptions, or be innovative, bold and aggressive in achieving the goals set out for you and your Ministry by the people of this province.*

The BC government describes the license evaluation process as follows on their website. See also Appendix D (excerpts from the Water Sustainability Act and Regulation) for more on groundwater licensing .

> *Applications undergo a technical review to make sure there is enough water at the source to issue a licence without affecting the existing water rights of others, or harming the water supply and aquatic ecosystem. Other government agencies, affected landowners and licensees may be notified of the application and given the chance to respond. First Nations in the area may also be consulted.*
>
> *The statutory decision maker… decides whether to approve [a] water licence after gathering information, giving notice to affected parties and considering objections. The decision maker takes many factors into account. Some of the deciding factors are mandatory under the WSA, such as considering environmental flow needs.*
>
> *The decision maker may refuse part or all of the application; require additional information and assessments; or grant all or part of the application and issue either a conditional or a final licence.*

The evaluation of license applications from Existing Use Groundwater Users is less stringent than applications from new groundwater users. In particular, Section 55(4) of the Regulation (Part 7 Transition - Groundwater Licensing) explicitly exempts applicants from meeting the needs of the environment.[8]

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[8] as defined in the Act: "environmental flow needs", in relation to a stream, means the volume and timing of water flow required for the proper functioning of the aquatic ecosystem of the stream. "Aquatic ecosystem, in relation to a stream, means the natural environment of the stream, including the stream channel, the vegetation in the stream and the water in the stream, and fish, wildlife and other living organisms insofar as their life processes are carried out in the stream, and depend on the natural environment of the stream;"

A BRIEF OVERVIEW OF GROUNDWATER RIGHTS

The system used by provincial governments to allocate water rights differs from province to province. In British Columbia, post-colonial water law is built on the principle of "First in Time, First in Right" (FITFIR). Under FITFIR, older licences for surface water have priority over newer ones during times of shortage. When the Act brought groundwater under provincial regulation in 2016, the FITFIR system was extended to groundwater licences as well. As noted, transitional groundwater users, such as CERMAQ and Natural Glacial Waters, have been allowed to continue diverting based on their historic use while their licence applications are pending. Their priority dates back to their first use (1990s and 1998, respectively). In contrast, residential wells do not require a license. The Act requires wells dug or drilled after 2016 be registered with the Water Management Branch, and owners of wells in place before 2016 are encouraged to also register to establish their history of use, but in fact many residential wells remain unregistered and their "first use" dates are undocumented. In our community, this means Cermaq and Natural Glacial Waters - both relative "newcomers" - hold more secure rights to our fragile aquifers than do many local families, who have depended on their wells for generations. And those rights persist, even as local wells are running dry.

In Fanny Bay, both Wilfred Creek and Waterloo Creek are aquifer-supported streams that provide salmon habitat. Over-pumping from Aquifer 419 and adjacent systems places fish survival and household water security at risk. Although Section 55(4) of the Regulation exempts Existing Use Groundwater license applicants from meeting the *environmental flow needs* provisions of the Act, it does not prevent temporary restrictions of their rights to withdraw groundwater in times of scarcity. In 2023, two Ministerial Orders were issued under Section 88, Division 5 of the Act that required a number of transitional users to temporarily cease groundwater diversion to protect salmon bearing streams on the Koksilah and Tsolum rivers.[9]

As *The Program on Water Governance* 2007 Fact Sheet: Water Rights Across Canada[10] notes, when it comes to water resources, Indigenous communities hold "first in use" place: "*…Prior to colonization, Aboriginal customs (or customary law) governed the use of water in Canada and continues to exist in tandem with Canadian law. Aboriginal rights and treaty rights, including certain customs and practices, became constitutionally protected in 1982. This means any rights, including water rights, not extinguished before 1982 can no longer be infringed upon by the government… There is the potential that Aboriginal and/or treaty rights to water "could govern water uses and take priority over all other uses (after ecological needs are met)."*[11]

Currently, FITFIR shields commercial groundwater extractors at the expense of residents and ecosystems. Alternative allocation systems for groundwater rights – for example one that regulates based on type of taking: groundwater withdrawal (water remains within the watershed, e.g. irrigation) as distinct from groundwater diversion (water is removed from the watershed) – should be considered.

RECOMMENDATION

That the Province of British Columbia:

1. Hold full and transparent public hearings as part of their consideration of groundwater licence applications for CERMAQ and Natural Glacial Waters.
2. Use powers under the Water Sustainability Act to impose timely restrictions on both transitional and licensed users during periods of drought.
3. Encourage public discussion of alternative groundwater allocation systems that more effectively recognize the sustainable rights of all stakeholders.

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[9] Province of British Columbia, Order of the Minister of Forests, Water Sustainability Act, Ministerial Order M241 Koksilah River (2023) and M249 Tsolum River (2023).

[10] Randy Christensen and Anastasia M. Lintner: Trading Our Common Heritage? The Debate over Water Rights Transfers in Canada" in Eau Canada, Ed. Karen Bakker, UBC Press: 2007

[11] Local First Nations communities traditionally harvested the sedge grass that grows on our foreshores for basket weaving. The head of one family that has continued this tradition for generations reports that, for the past several years, sedge grass has become harder and harder to find. (Pers. Com. Holm, 2024, 2025). Although there is no evidence of any connection, this is happening in the vicinity of Cermaq's plant which discharges groundwater used for fish rearing to (presumably) surface water flowing into the bay.

WHO IS FANNY BAY GROUNDWATER COLLECTIVE?

Per Rodney D. Zimmerman's Recommendation #5, Fanny Bay Groundwater Collective has been created to:

a. Provide Daniel Arbour, Director, Comox Valley Regional District Area A and other political and community leaders with a briefing document they can endorse and refer to Min. Neill to document the crisis facing Fanny Bay's groundwater resource (community wells drying up; multi-nationals in line for licences to continue to divert large volumes of water).
b. Convince government that a full and transparent public hearing process as part of any consideration of large-scale groundwater diversion licenses is good public policy critical to informed decision-making and the sustainable health of our aquifers.
c. Raise public awareness that groundwater - a good of the commons – is pivotal to drainage basin sustainability and that the long-term interest of the community must take precedence when deciding public policy.

Towards this end, the Fanny Bay Groundwater Collective has so far:

a. Entered into an agreement of collaboration and support with Beaufort Watershed Stewards.
b. Created a FB page to transparently share information (two-way process) with community members and assist in delivering a strong message to government.
c. Begun surveying area residents living between Station Road and Berray Road who depend on wells for their residential water supply to collect personal stories and identify those whose wells have run dry in the past three years.
d. Elicited the support of a videographer to produce a mini documentary on the Fanny Bay Groundwater Collective.

Next steps for the Fanny Bay Groundwater Collective include:

a. Circulate this briefing memo to those in a leadership role in our community to enlist their support.
b. Build public awareness (through a social media campaign) that encourages Minister Neill to commit to full public hearings as part of her consideration of any groundwater licenses for Natural Glacial Waters and Cermaq.
c. Provide support for a Resolution to the 2026 UBCM calling on provincial government to develop better policy and regulatory alternatives that will protect community rights to sustainable management of their local aquifers.
d. Support the development of an alternative, localized model for the allocation of groundwater rights that brings together the voices of all community stakeholders to protect the sustainability of our aquifers now and into the future.

APPENDIX A October 18, 1991 internal memo from Geological Engineer Rodney Zimmerman to Acting Head, Groundwater Section, Water Management Division, BC Environment re Fanny Bay – United Hatcheries Ltd.

APPENDIX B September 2024 correspondence from Beaufort Water Stewards to MLS Josie Osborne re Natural Glacier Waters and Lori Halls, DM, Min of Water, Land and Resource Stewardship's November 19, 2024 reply.

APPENDIX C Vancouver Island Groundwater Vulnerability Map

APPENDIX D Excerpts from 2016 Water Sustainability Act.

APPENDIX E *Unprecedented continental drying, shrinking freshwater availability, and increasing land contributions to sea level rise.* Hrishikesh A. Chandanpurkar, James S. Famiglietti, Kaushik Gopalan, David N. Wiese, Yoshihide Wada, Kaoru Kakinuma, John T. Reager, Fan Zhang. Science Advances Research Article Climatology. July 25, 2025.

APPENDIX A:

October 18, 1991 internal memo from Geological Engineer Rodney Zimmerman to Acting Head, Groundwater Section, Water Management Division, BC Environment re Fanny Bay – United Hatcheries Ltd.

APPENDIX A

Province of
British Columbia

B. C. Environment
Water Management Division
Parliament Buildings
Victoria, B.C.
V8V 1X5

MEMORANDUM

To: A. P. Kohut
Acting Head
Groundwater Section

Date: October 18, 1991

File: 92F/10 #39

Re: Fanny Bay - United Hatcheries Ltd.

Pursuant to your request of July 8, 1991, for a preliminary investigation regarding well interference complaints in the vicinity of United Hatcheries at Fanny Bay I would report as follows:

1. This investigation is subsequent to a letter dated June 12, 1991, from Mr. Jack Turner, Director, Electoral Area 'A', Regional District of Comox-Strathcona to Mr. A. Kohut, A/Head, Groundwater Section, and a reply to Mr. Turner dated July 5, 1991, advising that our staff will investigate the local groundwater conditions and provide recommendations which could assist in resolving the situation. Other relevant correspondence includes a letter to Mr. Jack Turner dated June 26, 1991, from Mr. J. R. Card, A/Regional Water Manager, Vancouver Island Region 1 and a letter to Mr. Jack Turner dated July 8, 1991, from Mr. D. A. Kasianchuk, Executive Director, Water Management Division, advising that our staff will investigate the local groundwater conditions and provide recommendations which could assist in resolving the situation.

2. A review of available hydrogeologic data and a field trip to the Fanny Bay area on July 18, 1991, have been completed. During the field trip meetings were held with John Slind of United Hatcheries and W. Carmichael and Carol McPherson of the Coal Creek Aquifer Protection Committee. Ms. McPherson has provided a map of the area showing the location and owners of many of the neighbouring wells. The Aquifer Protection Committee are collecting water level information from many of the wells and ponds in the vicinity.

3. The field trip was planned to coincide with a pump test of the wells at United Hatcheries. The wells are located adjacent to Wilfred Creek (Coal Creek) at the Fanny Bay site. Pumping from the wells may affect flow in the creek. Examination of the well logs and inspection of open cuts on the site indicate the aquifer being pumped may be semi-confined (The aquifer being comprised of fluvial, deltaic, and shore deposits of gravel, sand and silt). Without recording creek levels during a pump test it would not be

possible to estimate the influence of pumping on the creek. The distance between the well being pumped (W3) and the closest observation well is 30.9 m. The pump test rate was estimated to be between 650 to 750 USgpm. The operator was experiencing some difficulties with the pump. He thought it could possibly be a plugged screen on the pumped well. Some data was obtained at the time of the site visit and Mr. Slind provided some further data subsequent to completion of the pump test. The levels in the wells being tested had not yet stabilised at the time of the visit. Further data from the pump tests conducted by United Hatcheries will be required before a distance-drawdown relationship can be constructed. This relationship would define the extent of interference drawdown in the neighbouring wells and ponds due to various rates of pumping at the hatchery wells and determine which well levels in the vicinity have declined due to a general seasonal decline in water levels. The Garnier wells on Stelling Road were also inspected. The older and shallower well may be suitable for monitoring purposes.

4. Table 1, attached, lists the known wells in the vicinity. The locations of these wells are shown on Maps 92F.046.4.4 and 92F.047.3.3 included with this memorandum. Many of the older wells are shallow dug wells. The records of many newer drilled wells are currently not available; such as, the private wells along Stelling Road.

5. The pumping schedule proposed by United Hatcheries at Fanny Bay for 1991 and 1992 is:

	L/m	USgpm
Aug 1, 1991	3,000	792.5
Sept 1, 1991	3,500	924.6
Oct 1, 1991	6,000	1,585.0
Nov 1, 1991	10,000	2,641.7
Dec 1, 1991	10,000	2,641.7
Jan 1, 1992	12,000	3,170.1
Feb 1, 1992	12,000	3,170.1
Mar 1, 1992	14,000	3,698.4
Apr 1, 1992	15,000	3,962.6
May 1, 1992	8,000	2,113.4
June 1, 1992	2,000	528.3

Conclusions:

1. Pumping at the United Hatchery site is interfering to some degree with some of the neighbouring wells and ponds. The extent and magnitude of this interference and the number of affected wells is not known precisely at this time. The wells which are affected could be drilled to a greater depth to ensure a continued

domestic supply. There would appear to be adequate quantities of groundwater available to meet present demands.

2. It is possible, depending on pumping levels at the hatchery site, that saline water may advance further into the freshwater aquifer due to increased groundwater withdrawals. This may be a concern at the marsh areas around Little Bay.

Recommendations:

1. It is recommended United Hatcheries retain a groundwater consultant to prepare a report summarizing the results of the pump testing and to include a distance-drawdown relationship and any proposed strategies to mitigate the effects of any excessive well interference on neighbouring wells and ponds. The effect of pumping on the adjacent creek should also be documented.

2. It is recommended groundwater level and quality monitoring wells be established between the hatchery site and White Duck Road and adjacent to the marsh at Little Bay.

3. The information being collected by the Aquifer Protection Committee should be compiled, the locations mapped and readings referenced to a common datum. A door to door well inventory should be undertaken and information compiled on all new wells in the area to assess current groundwater use.

4. The feasibility of supplying residents from other water supply alternatives should be assessed.

5. As groundwater withdrawals are currently not subject to regulatory controls under Provincial legislation the major groundwater users in the area might wish to consider establishing an informal committee where the various parties involved could work together in developing a local management strategy, including monitoring, for the aquifer and to their mutual benefit.

Rodney D. Zimmerman

Rodney D. Zimmerman
Geological Engineer
Groundwater Section

Ministry of Environment - Water Management Branch - Groundwater Section

Groundwater Database System

Data Summary - with Legal Descriptions and Old Coordinates

BCGS Map Area	Well No.	Lot No.	Plan No.	Blk No.	TP	SC	RG	D.L.	Z	X	Y	Old Well No.	L.D.	Owner'sName		Phone Number	Site Address	Date Constructed (dmy)	Well Depth (ft.)	Well Diam. (in.)	Drill Contr No.	Const. Method	Well Yield	Yld. Unt.	Depth to Water (ft.)	Depth to Bedrk (ft.)	Aquif Litho	Screen Interval (ft.)	G.W. Rpt	Chem Lab	Chem Rd	Chem Site No.
092F.046.4.4.1	1	88							0	19	13	1	36	QUALICUM VILLAGE				1-Jan-50	193		UNK	OTH			UNK	UNK	UNC					
092F.046.4.4.2	1	23							0	21	14	4	36	ISABLE LOGGING CO				1-Jan-50			UNK				UNK	UNK	UNC					
092F.046.4.4.4	1	6AG							0	20	14	1	36	D E MCMILLAN				1-Jan-50			UNK				UNK	UNK	UNC					
092F.046.4.4.4	2	6AG							0	20	14	2	36	HALGREN				1-Jan-50	12	4	UNK	DUG			UNK	UNK	UNC					
092F.046.4.4.4	3	6AG							0	20	14	3	36	A WARREN				1-Jan-50	12		UNK	DUG			6	UNK	UNC					
092F.046.4.4.4	4	48							0	20	14	4	36	STOP & SHOP STORE				1-Jan-50	25		UNK	DUG			5	UNK	UNC					
092F.046.4.4.4	5	23							0	21	14	1	36	J MARTIN			Stelling Road	1-Jan-50	18		UNK	DUG			15	UNK	UNC					
092F.046.4.4.4	6	30							0	21	14	6	36	C LITTLE				1-Jan-50	18		UNK	DUG			UNK	UNK	UNC					
092F.046.4.4.4	7	47							0	21	14	7	36	COMMUNITY HALL				1-Jan-50	25		UNK	DUG			23	UNK	UNC					
092F.046.4.4.4	8	A	21494			2			0	21	14	8	36	TOZER CONSTRUCTION	Gunter Spring			1-Jan-50			UNK				UNK	UNK	UNC					
092F.046.4.4.4	9	30							0	21	14	10	36	C LITTLE	Rick Bullen?			1-Jan-50	9		UNK	DUG			5	UNK	UNC					
092F.046.4.4.4	10								0	0	0	0	36	PHILLIPS			SHIPS POINT	14-Apr-80	40	6	43	DRI	15	GPM	UNK	UNK	UNC					
092F.046.4.4.4	11								0	0	0	0	36	TREL HOLR KAMP	Austin Dunbar?		SHIPS POINT RD	12-Jul-78	32	5	69	DRI	30	GPM	15	UNK	UNC	20-30				
092F.047.3.3.1	1	5							0	21	13	1	36	A HASTINGS				1-Jan-50	12		UNK	DUG			12	UNK	UNC					
092F.047.3.3.1	2	5							0	21	13	2	36	E OLINS				1-Jan-50	12		UNK	DUG			8	UNK	UNC					
092F.047.3.3.1	3	12							0	21	13	7	36	T ADAIR				1-Jan-50	15		UNK	DUG			13	UNK	UNC					
092F.047.3.3.1	4	12							0	21	13	8	36	M JACKSON				1-Jan-50	10		UNK	DUG			8	UNK	UNC					
092F.047.3.3.1	5	23							0	21	13	9	36	J E FLETCHER				1-Jan-50			UNK	OTH			UNK	UNK	UNC					
092F.047.3.3.1	6	23							0	21	14	2	36	Dick Dennison ?		335-2763		1-Jan-50	15		UNK	DUG			12	UNK	UNC					
092F.047.3.3.1	7	23							0	21	14	3	36	M STILLING				1-Jan-50	10		UNK	DUG			5	UNK	UNC					
092F.047.3.3.3	1	30							0	21	14	5	36	E TAYLOR				1-Jan-50	8		UNK	DUG			3	UNK	UNC					
092F.047.3.3.3	2	30							0	21	14	9	36	DENISON	Obbie Dennison F15	335-2763		1-Jan-50	11		UNK	DUG			7	UNK	UNC					
092F.047.3.3.3	3								0	21	14	11	36	SHIP POINT SUBDIVISION		335-0357	SHIP POINT	1-Jan-67	16		UNK	DUG	235	GPM	UNK	UNK	UNC			Y		
	F1													George Sawchuk		335-0682																
	F2													Rick Bullen		335-0210																
	F3													Mike Williams		335-0209																
	F4													Will Gregor		335-0107																
	F5													Diane Harris		335-2451																
	F6													Norm Wilson		335-0010																
092F.046.4.4.4	11	?												Austin Dunbar		335-0503																
	F7													Dennis Garnier		335-2434																
092F.047.3.3.1	67	F8												Dick Dennison		335-2763																
	F9													Vern Petch		335-2522																
	F10													Ted Trew		335-0598																
	F11													Jim Ackincose		335-0010																
	F12													Ken Giles		335-0598																
	F13													H. Hume		335-2557																
	F14													Len Dodds		335-0002																
092F.047.3.3.1	8													United Fish Hatchery																		
092F.047.3.3.1	9													United Fish Hatchery																		
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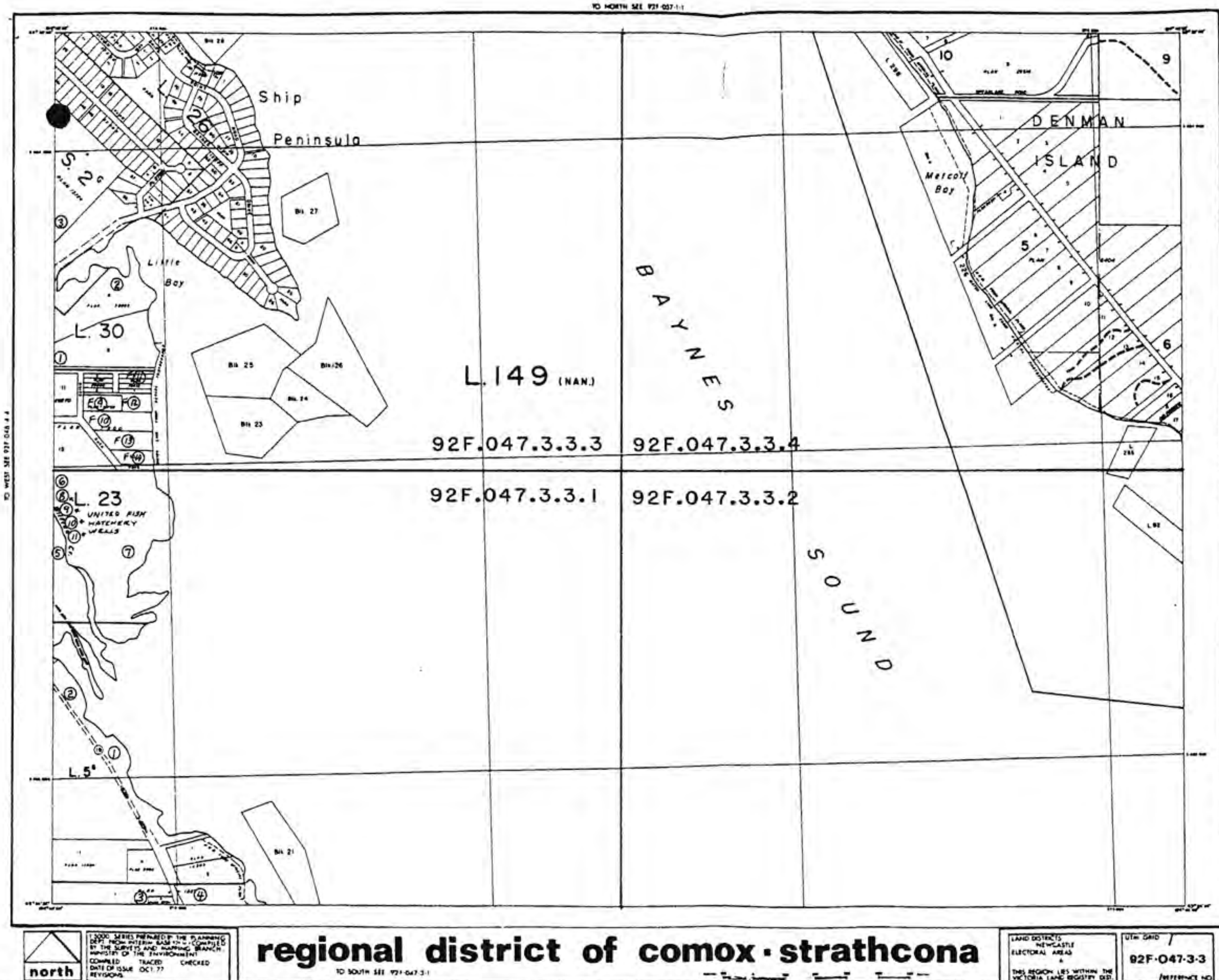
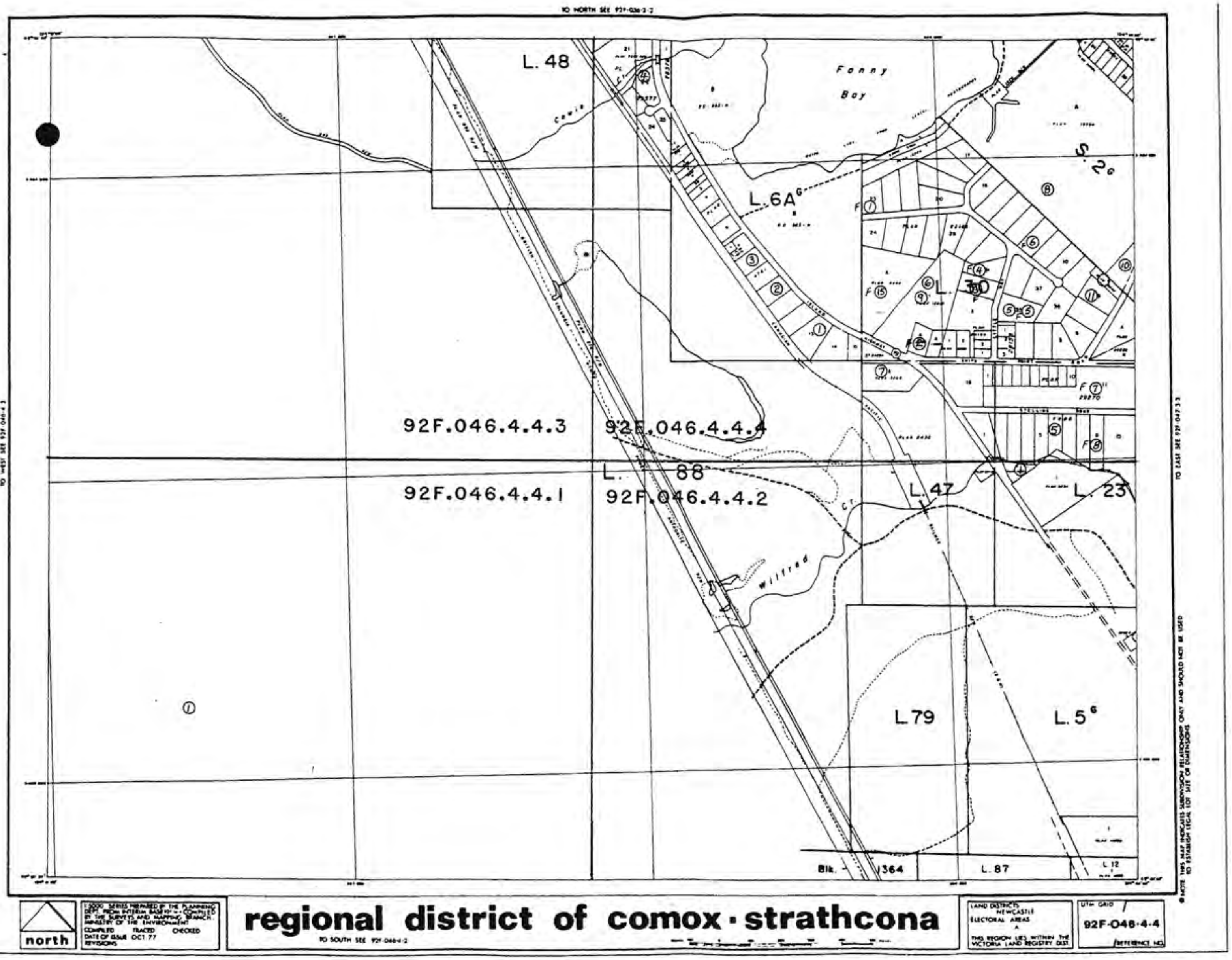


LEGEND

③ Existing Well



LEGEND

⑨ Existing Well

APPENDIX B

Water Extraction for International Export – at What Risk to Local Aquifers? Beaufort Watershed Stewards September 27, 2024

September 16, 2024 letter from Beaufort Water Stewards to MLS Josie Osborne regarding Natural Glacier Waters

November 19, 2024 reply from Lori Halls, DM, Min of Water, Land and Resource Stewardship to Beaufort Watershed Stewards re Natural Glacial Waters.

Water Extraction for International Export: At what risk to local aquifers?

By Lynne Ray

27 September, 2024

Some residents along the eastern slopes of the Beaufort Range are aware of the Natural Glacial Waters bottling plant near Rosewall Creek in Fanny Bay. Since 1997 this plant has been extracting aquifer water and shipping it to Asian markets. While the BC Water Protection Act prohibits bulk export of water, if packaged in bottles less that 20 litres, any amount of water can be exported. Natural Glacial Waters has applied to the province for a license renewal. The application is to extract an average of 5 million litres of water from the aquifer per day. The term of these licenses can be 30 years.

Beaufort Watershed Stewards are deeply concerned about the unknown effects on the local aquifers that we depend on for all our water. We conduct ground water monitoring, aquifer mapping, and stream sampling in the area and have found that there is insufficient scientific data to conclude that this large scale water extraction and export is a safe practice. We have submitted the following letter to our local Minister for Mid Island-Pacific Rim, Josie Osborne. We encourage you to submit letters to your local MLA, and the Honourable Nathan Cullen, Minister of Water, Land and Resource Stewardship. Following our letter is a template to get you started.

Thank you for your concerns and action regarding smart stewardship of our water resources.

Beaufort Watershed Stewards
PO Box 253, Union Bay, BC V0R 3B0
www.beaufortwater.org
info@beaufortwater.org

16 September 2024

Honourable Josie Osborne, MLA for Mid Island-Pacific Rim
Minister of Energy, Mines and Low Carbon Innovation
Via email: EMLI.minister@gov.bc.ca

RE: Natural Glacial Waters Groundwater Extraction License Application

Dear Minister Osborne,

We are writing to express our concerns about the Natural Glacial Waters existing use water extraction license application to extract and export ground water. The plant is located on Berray Road beside Rosewall Creek in Fanny Bay. The application is to extract 1,892,160 m^3/year of water from the aquifer[1] for export. Due to a loophole in the Water Protection Act, this is not considered bulk export if packaged in bottles less than 20 litres.[2]

Beaufort Watershed Stewards is a science-based non-profit organization working on the eastern slopes of the Beaufort Mountain Range on Vancouver Island. Our mission is to work to promote the health and resilience of local watersheds in the Beaufort Range and to ensure the quality and quantity of fresh water for the future.[3] We collect data using six watershed assessment pillars, three of which inform this letter: geophysical aquifer mapping, groundwater well monitoring and stream flow monitoring in selected creeks.

The aquifer boundaries in the Rosewall Creek area have not been mapped in any detail and are largely derived from surficial geology studies done by Bednarski et al. (2015) [4] and Fyles (1963). [5] In collaboration with the University of Victoria – Environmental Earth and Ocean Sciences we have been using geophysical Vertical Electric Soundings (VES) to better define subsurface structures and aquifer distribution in our area. We have done several VES in the Rosewall Creek area.

As part of our groundwater monitoring program, we monitor both level and specific conductivity in an unused well located on Berray Rd within the proximity of the bottling plant. We also collaborate with the BC Conservation Foundation and have been tracking stream flow in creeks in the area of Rosewall Creek.

What our data indicate, is that there is not sufficient knowledge of the aquifer's size, refresh capacity and resilience to approve freshwater extraction in the quantities specified in the Natural Glacial Waters' application. Given the threats of climate change, recurring droughts and increasing demand for residential water use, extraction and exportation of water in this volume places local water sustainability at risk. Further, approval of a thirty-year license is rash in the extreme.

Given these issues, Beaufort Watershed Stewards must express opposition to the approval of this license. We look forward to your response and action taken on the issue of water extraction and exportation.

Sincerely,

Dave Weaver, President
Beaufort Watershed Stewards

Cc: Honourable Nathan Cullen, Minister of Water, Land and Resource Stewardship
K'ómoks First Nation, Chief Councillor Ken Price
Qualicum First Nation, Chief Councillor Michael Recalma

Footnotes:

1 Ministry of Forests correspondence, 23 February 2023.

2 https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/laws-rules/water-protection-act

3 www.beaufortwater.org

4 Bednarski, J. M., 2015. Surficial Geology and Pleistocene stratigraphy from Deep Bay to Nanoose Harbour, Vancouver Island, British Columbia. Geological Survey of Canada, Open File 7681, 1 zip file, DOI:10.4095/295609.

5 Fyles, J.G. 1963a. Surficial geology of the Horne Lake and Parksville map-areas, Vancouver Island, British Columbia. Memoir 318. Geological Survey of Canada: Ottawa, ON.

BRITISH
COLUMBIA

Reference: 43271

November 19, 2024

VIA EMAIL: president@beaufortwater.org

Dave Weaver, President
Beaufort Watershed Stewards
PO Box 253
Union Bay, British Columbia
V0R 3B0

Dear Dave Weaver:

Thank you for your letter of September 15, 2024, regarding the existing use water extraction license application for Natural Glacial Waters Inc. This topic falls under the purview of the Ministry of Water, Land and Resource Stewardship (WLRS); as Deputy Minister, I have been asked to respond.

The application you reference was submitted to comply with the *Water Sustainability Act* (WSA) as a "transitioning groundwater user." The WSA, effective February 29, 2016, created a requirement for non-domestic groundwater users to apply for water licences for the first time in British Columbia (B.C.). "Transitioning groundwater users" are those already using groundwater for non-domestic purposes before the WSA was implemented. "New users" are those without a prior history of groundwater use.

Transitioning groundwater users were required to apply for an existing use groundwater licence by March 1, 2022. These users benefit from a unique application process which allows them to acquire a date of seniority, based on the date their use of water began. Transitioning groundwater users are also allowed to continue diverting water consistent with their historical practices as they await a decision on their application. You can learn more about types of groundwater users and their requirements here: Groundwater Use Requirements.

The Fanny Bay operations of Natural Glacial Waters Inc. submitted their transitioning groundwater user application in 2019, in compliance with the deadline. Their application advises they have been diverting 1,892,160 cubic metres per year from Aquifer 414 since July 1, 1998. This application has not yet been processed. If the

Ministry of Water, Land and Resource Stewardship | Office of the Deputy Minister | Mailing Address: PO Box 9367 Stn Prov Govt Victoria, BC V8W 9M3 | Tel: 778 445-4757 Website:www.gov.bc.ca/WLRS

decision maker decides to grant this application, licence documents will be made available on the Water Licence Search tool.

Decisions on issuing or denying a water licence are based on supply and demand analyses, sustainability principles, and water authorizations already issued on the same or hydraulically connected sources. When applications for transitioning groundwater users are processed, the Province also confirms that the volume of water requested is consistent with historical use practices. For that reason, granting a transitioning groundwater user licence typically does not authorize a new additional use of the water source. Further, if a licence is granted, the licensee must use the water subject to the terms and conditions of their authorization and any additional directions received by WSA statutory decision makers.

Regarding local water sustainability during times of water scarcity, if a fish population is threatened or likely to become threatened due to water use, the Minister can curtail water use through a temporary protection order.

You also raised concerns about the *Water Protection Act* (WPA), which sets out that water bottlers who export water in containers of 20-litre capacity or less are exempt from the WPA's bulk export prohibitions. While true, anyone who diverts and uses water in B.C. is subject to authorization requirements under the WSA and must apply for and acquire a license; comply with any terms and conditions on that licence; and comply with all other applicable legislation and regulations. Should a licence holder fail to meet these requirements, compliance and enforcement actions may be considered.

For more information on aquifers and Groundwater Wells and Aquifers applications (GWELLS), you can visit these websites: Understanding Aquifers and aquifer 414.

Lastly, you mentioned that Beaufort Watershed Stewards monitor and collect data in the Rosewall Creek watershed. WLRS often receives data from non-government parties to help inform watershed and aquifer stewardship priorities. If you are willing to share your data, please contact Jessica Doyle, Water Protection Section Head, in the West Coast Region at jessica.doyle@gov.bc.ca.

Thank you for writing and sharing your concerns.

Sincerely,

Lori Halls

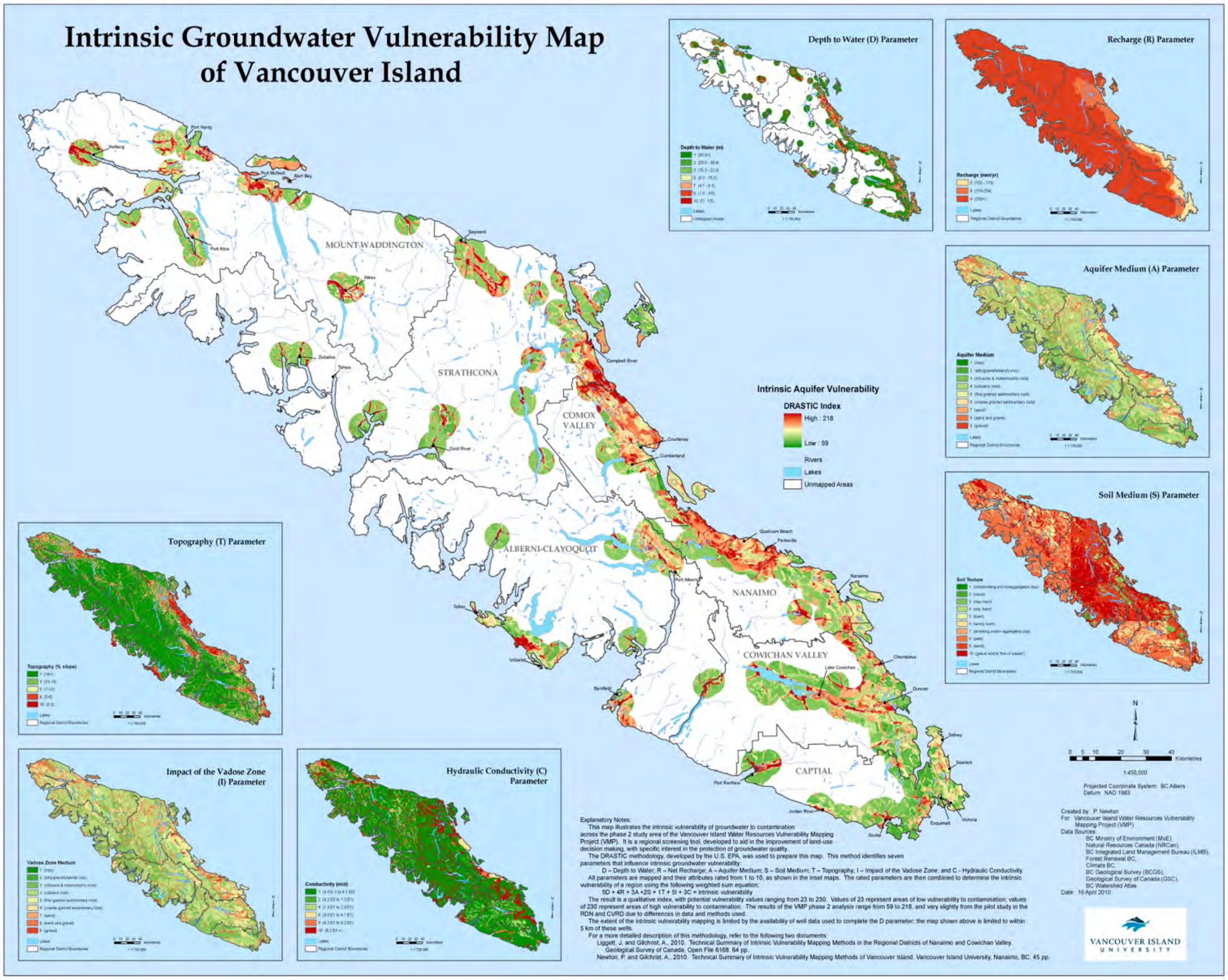
Lori Halls
Deputy Minister

pc: Jessica Doyle, Water Protection Section Head, Ministry of Water, Land and Resource Stewardship

APPENDIX C

Vancouver Island Groundwater Vulnerability Map

APPENDIX C



Intrinsic Groundwater Vulnerability Map of Vancouver Island
Depth to Water (D) Parameter
Recharge (R) Parameter
Aquifer Medium (A) Parameter
Soil Medium (S) Parameter
Topography (T) Parameter
Impact of the Vadose Zone (I) Parameter
Hydraulic Conductivity (C) Parameter
MOUNT WADDINGTON
STRATHCONA
COMOX VALLEY
ALBERNI-CLAYOQUOT
NANAIMO
COWICHAN VALLEY
CAPTIAL
Port Hardy
Port McNeill
Port Alice
Campbell River
Courtenay
Cumberland
Gold River
Port Alberni
Qualicum Beach
Parksville
Nanaimo
Lake Cowichan
Chemainus
Duncan
Port Renfrew
Jordan River
Sooke
Sidney
Saanich
Esquimalt
Victoria
Intrinsic Aquifer Vulnerability
DRASTIC Index
High : 218
Low : 59
Rivers
Lakes
Unmapped Areas
N
0 5 10 20 30 40 Kilometres
1:450,000
Projected Coordinate System: BC Albers
Datum: NAD 1983
Created by: P. Newton
For: Vancouver Island Water Resources Vulnerability Mapping Project (VMP)
Data Sources:
BC Ministry of Environment (MoE),
Natural Resources Canada (NRCan),
BC Integrated Land Management Bureau (ILMB),
Forest Renewal BC,
Climate BC,
BC Geological Survey (BCGS),
Geological Survey of Canada (GSC),
BC Watershed Atlas
Date: 16 April 2010
Explanatory Notes:
This map illustrates the intrinsic vulnerability of groundwater to contamination across the phase 2 study area of the Vancouver Island Water Resources Vulnerability Mapping Project (VMP). It is a regional screening tool, developed to aid in the improvement of land-use decision making, with specific interest in the protection of groundwater quality.
The DRASTIC methodology, developed by the U.S. EPA, was used to prepare this map. This method identifies seven parameters that influence intrinsic groundwater vulnerability:
D – Depth to Water; R – Net Recharge; A – Aquifer Medium; S – Soil Medium; T – Topography; I – Impact of the Vadose Zone; and C - Hydraulic Conductivity.
All parameters are mapped and their attributes rated from 1 to 10, as shown in the inset maps. The rated parameters are then combined to determine the intrinsic vulnerability of a region using the following weighted sum equation:
5D + 4R + 3A +2S + 1T + 5I + 3C = intrinsic vulnerability
The result is a qualitative index, with potential vulnerability values ranging from 23 to 230. Values of 23 represent areas of low vulnerability to contamination; values of 230 represent areas of high vulnerability to contamination. The results of the VMP phase 2 analysis range from 59 to 218, and vary slightly from the pilot study in the RDN and CVRD due to differences in data and methods used.
The extent of the intrinsic vulnerability mapping is limited by the availability of well data used to complete the D parameter; the map shown above is limited to within 5 km of these wells.
For a more detailed description of this methodology, refer to the following two documents:
Liggett, J. and Gilchrist, A., 2010. Technical Summary of Intrinsic Vulnerability Mapping Methods in the Regional Districts of Nanaimo and Cowichan Valley. Geological Survey of Canada, Open File 6168. 64 pp.
Newton, P. and Gilchrist, A., 2010. Technical Summary of Intrinsic Vulnerability Mapping Methods of Vancouver Island. Vancouver Island University, Nanaimo, BC. 45 pp.
VANCOUVER ISLAND UNIVERSITY

APPENDIX D

Excerpts from:

2016 Water Sustainability Act

Water Sustainability Regulation.

APPENDIX D

Sections Excerpted from Water Sustainability Act [SBC 2014] Chapter 15 and Water Sustainability Regulations

Water Sustainability Act

Licences

9 On application in accordance with section 12 *[application and decision maker initiative procedures]*, the comptroller or a water manager may issue a licence, authorizing the diversion or use of water for one or more water use purposes, to any of the following:

a) an owner of land or a mine;
b) a holder of a certificate of public convenience and necessity issued under the *Public Utilities Act*, R.S.B.C. 1960, c. 323, the *Utilities Commission Act* or the *Water Utility Act*;
c) a municipality, regional district, improvement district, development district or water users' community;
d) the government of British Columbia or Canada;
e) a commission, board or person having charge of the administration of Crown land or a mine or an undertaking on Crown land, administered by British Columbia or Canada or controlled by a ministry, department, branch or other subdivision of the government of British Columbia or Canada;
f) the Greater Vancouver Water District or any other water district incorporated by an Act;
g) the British Columbia Hydro and Power Authority.

Use approvals

10 (1) On application in accordance with section 12 *[application and decision maker initiative procedures]*, the comptroller or a water manager may issue an approval for one or more water use purposes authorizing any of the following to divert or use water from a stream or an aquifer for a term not exceeding 24 months:

a) the government of British Columbia or Canada;
b) another person.

(2) A use approval under this section must not authorize

a) the diversion or use of more than the prescribed quantity of water,
b) the diversion or use of water for a prescribed water use purpose, or
c) the construction, maintenance or use of prescribed works.

(3) For certainty, a use approval may be issued authorizing a person to divert water from a source of water supply for a water use purpose in relation to an appurtenancy, if any, specified in the use approval, whether or not a use approval was previously issued authorizing the person to divert water from the same water source supply for the same water use purpose in relation to the same appurtenancy.

Changes in and about a stream

11 (1) On application in accordance with section 12, the comptroller, a water manager or an engineer may issue an approval authorizing any of the following persons to make changes in and about a stream:

a) the government of British Columbia or Canada;
b) another person.

(2) Changes in and about a stream may only be made in accordance with

a) the terms and conditions of a change approval,
b) the regulations,
c) the terms and conditions of an authorization, or
d) an order.

Application and decision maker initiative procedures

12 (1) An applicant may apply to a decision maker by

a) complying with any requirements prescribed in respect of the application, and
b) within the period, if any, prescribed by regulation,
    I. complying with the decision maker's directions under section 13 (1) or (9), if any,
    II. paying the prescribed fees,
    III. providing in the form and manner specified by the decision maker any plans, specifications, reports of assessments and other information the decision maker requests, which information may include, but is not limited to, public personal information that is relevant to the application, respecting
        A. the applicant,
        B. existing water users, riparian owners, other applicants and other authorization holders, whose rights are likely to be detrimentally affected if the application is granted, and
        C. land owners whose land is likely to be physically affected if the application is granted, and
    IV. providing in the form and manner specified by the decision maker the consents that are necessary for the decision maker to verify personal information relating to the applicant that is provided under subparagraph (iii).

2) For the purposes of subsection (1) (b) (iii), the decision maker may require that a specified assessment be performed, and a report of the assessment be prepared, by a person with the qualifications specified by the decision maker.

3) For the purpose of making a decision on an application, the decision maker may
   a) collect contact information from the applicant, and collect public personal information and government water records, related to a person referred to in subsection (1) (b) (iii), and
   b) verify information collected under this subsection or provided under subsection (1) or (2), including, in relation to
      I. personal information of the applicant, by consent or by reference to public personal information or government water records, and
      II. personal information of a person referred to in subsection (1) (b) (iii) (B) or (C), by direct contact with the person or by reference to public personal information or government water records.
4) If works are required to be constructed in order for the applicant to obtain information required for the purposes of subsection (1) (b) (iii), the applicant may construct, in accordance with any applicable regulations, the works for that purpose, subject to any applicable requirement for a drilling authorization in relation to the works.
5) The decision maker may
   a) shorten or extend the period prescribed for the purposes of subsection (1) (b), or
   b) if no period has been prescribed, set a period for compliance with a direction or request, if any, referred to in subsection (1) (b).
6) A decision maker may exercise the powers under this section in relation to an initiative of the decision maker under section 21 *[when final licence may be issued]*, 26 *[amendment or substitution of authorization, change approval or permit]*, 28 *[apportionment of rights under licences]* or 62 *[drilling authorizations]*.

Objections to applications and decision maker initiatives

13 (1) A decision maker must direct that an applicant for a licence, use approval or change approval, or for an amendment to any of them involving a change of works, give notice of the application in accordance with section 117 *[delivery and publication of documents and information]* or the regulations to
   a) any of the following whose rights the decision maker considers are likely to be detrimentally affected if the application is granted:
      I. an authorization holder;
      II. a change approval holder;
      III. an applicant for an authorization or change approval;
      IV. a riparian owner, and
   b) a land owner whose land is likely to be physically affected if the application is granted.
2) A notice under subsection (1) must include the name of the decision maker and the address to which objections to the application may be delivered.
3) A person who is given notice under subsection (1) may deliver to the decision maker identified in the notice within the prescribed period any objection the person has to the granting of the application.
4) If an objection is delivered in accordance with subsection (3), the decision maker must decide whether or not the objection warrants a hearing.
5) If the decision maker decides to hold a hearing, the decision maker must
   a) give notice to the applicant and to any person who delivered an objection under subsection (3) of
      I. the date, time and location of the hearing, or
      II. the date by which written submissions must be received by the decision maker, and
   b) give the applicant and the objectors the opportunity to be heard in the hearing.
6) The decision maker may hold a hearing in writing, electronically or in person or by any combination of written, electronic or in-person hearings and, if the hearing is held orally, either in person or electronically, sections 95 *[inquiry powers]*, 96 *[maintenance of order at hearings]* and 97 *[contempt proceeding for uncooperative person]* apply.
7) The decision maker must give notice of the decision maker's decision on an application to any person who delivered under subsection (3) an objection in relation to the application.
8) For certainty, a decision maker need not give directions under subsection (1) if the decision maker is satisfied that, as a result of the decision maker's decision on an application referred to in that subsection,
   a) no authorization holder's rights, no change approval holder's rights and no riparian owner's rights will be detrimentally affected,
   b) no person's land will be physically affected, and
   c) no person's application for an authorization or a change approval will be detrimentally affected.
9) A decision maker may direct that any applicant, and in the case of a transfer under section 27 *[transfer of appurtenancy]*, the transferee, give notice in accordance with section 117 or the regulations,
   a) in the case of an apportionment under section 28 *[apportionment of rights under licences]*, to the owner of each parcel affected by the apportionment,
   b) in the case of an abandonment of rights under section 31 *[abandonment of rights under an authorization]*, to anyone who is jointly using works with the applicant and any person whose land is physically affected by the existing works, and
   c) in any case, to any person whose input into the decision the decision maker considers advisable.
10) Subsections (2) to (7) apply if notice is given under subsection (9) (a) or (b).
11) Despite subsection (10), if a decision maker gives, or requires to be given, notice under subsection (9), the decision maker may specify how, and the date by which, a person given notice may object to the application.
12) A person given notice under subsection (9) (c) is not entitled to be heard in a hearing under this section.
13) If a decision maker initiates the issuance of a final licence under section 21 *[when final licence may be issued]*, a 30-year review under section 23, an amendment under section 26 *[amendment or substitution of authorization, change approval or permit]* or an

apportionment under section 28, subsections (9) to (12) of this section apply unless the amendment requires a change of works, in which case subsections (1) to (8) and (14) of this section apply.

14) Instead of requiring the applicant or a transferee to give a notice required under subsection (1) or (9), the decision maker may give the notice.

Powers respecting applications and decision maker initiatives

14 (1) Whether or not notice is given, or objections are delivered, under section 13 in relation to an application, the decision maker may, in accordance with this Act and the regulations,

a) refuse the application,
b) amend the application in any respect,
c) grant all or part of the application,
d) order the applicant to provide in the form and manner specified by the decision maker plans, specifications, reports of assessments or other information, which information may include, but is not limited to, public personal information that is relevant to the application, respecting
    I. the applicant,
    II. existing water users, riparian owners, other applicants and other authorization holders, whose rights are likely to be detrimentally affected if the application is granted, and
    III. land owners whose land is likely to be physically affected if the application is granted,
e) order the applicant to provide security to the decision maker in the amount the decision maker considers sufficient to ensure the performance of the applicant's obligations under this Act and the authorization, change approval or drilling authorization, as applicable, that is issued to the applicant, or
f) issue to the applicant, subject to prescribed terms and conditions and on the terms and conditions the decision maker considers advisable,
    I. one or more conditional licences or final licences, or
    II. a use approval, a change approval or a drilling authorization, as applicable.

2) An applicant must comply with an order made under subsection (1) (d) or (e) within the period specified by the decision maker.
3) For the purposes of subsection (1) (d), the decision maker may require that a specified assessment be performed, and a report of the assessment be prepared, by a person with the qualifications specified by the decision maker.
4) If an application is for the purpose of diverting water from an aquifer, the decision maker must take into account the quantity of water persons to whom section 6 (4) *[use of water — excluded groundwater users]* applies are authorized to divert from the aquifer.
5) In considering an application for a new licence that relates to the region as defined by the *Columbia Basin Trust Act*, the decision maker must consider the current long term Columbia Basin Management Plan under section 15 *[Columbia Basin Management Plan]* of that Act.
6) Without limiting subsection (1), the decision maker may refuse an application, or reject an application without considering it, if
    a) the applicant fails to comply with
        I. section 12 (1) *[application and decision maker initiative procedures]*,
        II. a direction under section 13 (1) or (9),
        III. an order under subsection (1) (d) or (e) of this section, or
        IV. an order or a direction referred to in this paragraph within the required period,
    b) in the case of an application for a use approval or change approval, the decision maker considers the proposed use of water or the proposed works would be more properly authorized by licence, or
    c) the application is incomplete.
7) (A decision maker must refuse to accept an application or a part of an application that would result in the issuance of an authorization to a person to whom section 6 (4) *[use of water — excluded groundwater users]* applies.
8) A decision maker may not issue a licence authorizing the diversion or use of dedicated agricultural water unless the licence is for a qualifying agricultural use on qualifying agricultural land.
9) Despite subsection (8), a licence may be issued authorizing the diversion or use of unrecorded dedicated agricultural water for domestic purpose or a land improvement purpose.
10) A decision maker may exercise the powers under this section in relation to an initiative of the decision maker under section 21 *[when final licence may be issued]*, 26 *[amendment or substitution of authorization, change approval or permit]*, 28 *[apportionment of rights under licences]* or 62 *[drilling authorizations]*.
11) For certainty, a use approval may be issued authorizing the diversion or use of unrecorded dedicated agricultural water for any water use purpose on any land.

Environmental flow needs

15 (1) Except in relation to an application exempted under the regulations, the decision maker must consider the environmental flow needs of a stream in deciding an application in relation to the stream or an aquifer the decision maker considers is reasonably likely to be hydraulically connected to that stream.

2) For an application in respect of which the decision maker must consider, or decides under subsection (4) to consider, the environmental flow needs of a stream,
    a) the applicant must provide to the decision maker the information and reports of assessments the decision maker directs for the purposes of paragraph (b) of this subsection, and
    b) the decision maker must determine, in accordance with any applicable regulations, the environmental flow needs of the applicable stream.

3) For the purposes of subsection (2) (a), the decision maker may require that a specified assessment be performed, and a report of the assessment be prepared, by a person with the qualifications specified by the decision maker.
4) Despite subsection (1), a decision maker may take into account the environmental flow needs of any stream the decision maker considers may be affected by granting the application.

Mitigation measures

16 (1) If the decision maker considers that the diversion and use of water, or changes in and about a stream, proposed by an application for an authorization, or the changes in and about a stream proposed to be made under a change approval, are likely to have a significant adverse impact on the water quality, water quantity or aquatic ecosystem of a stream or aquifer, a stream channel or other uses of water from the stream or aquifer to which the application relates, the decision maker may

a) require that the applicant submit a proposal for mitigation measures to address those effects, which mitigation measures must meet prescribed criteria, if any, and
b) impose under section 14 (1) (f) *[powers respecting applications and decision maker initiatives]* terms and conditions requiring implementation of the proposed mitigation measures if those measures meet the prescribed criteria.

2) If the decision maker considers that the effects described in subsection (1) cannot be addressed, or cannot be fully addressed, by mitigation measures proposed by the applicant but can be compensated for by other mitigation measures taken on a different part of the stream or aquifer than the part to which the proposal relates, the decision maker may impose under section 14 (1) (f) terms and conditions requiring the applicant to take compensatory mitigation measures that meet the prescribed criteria, in place of or supplemental to any mitigation measures proposed by the applicant, on a different part of the stream or aquifer to which the application relates.
3) With the consent of the applicant, the terms and conditions of an authorization or change approval may require that the applicant take compensatory mitigation measures on a different stream or aquifer than the stream or aquifer in respect of which the application is made.

Sensitive streams mitigation

17 (1) If an application for an authorization or a change approval, or an amendment to an authorization or change approval, is in relation to a sensitive stream, the decision maker

(a) may require that the applicant provide the prescribed plans, specifications, reports of assessments or other information, in addition to the other information required under this Act in relation to the application, and
(b) must apply prescribed criteria, if any, in addition to the other criteria to be applied under this Act, in deciding whether to grant the application.

2) An application described in subsection (1) must include mitigation measures that meet the prescribed criteria, if any, and that the applicant proposes to take to mitigate any adverse impact on a protected fish population resulting from granting the application in relation to the sensitive stream.
3) The decision maker may grant an application described in subsection (1) only
   a) if satisfied that
      I. any adverse impact, resulting from granting the application, on the sustainability of any protected fish population of the sensitive stream is likely to be insignificant,
      II. the mitigation measures proposed by the applicant, if carried out, would ensure that granting the application is not likely to cause a significant adverse impact on any protected fish population or the aquatic ecosystem of the sensitive stream, or
      III. compensatory mitigation measures that meet any prescribed criteria, whether or not proposed by the applicant, if carried out, in place of or supplemental to the proposed mitigation measures, will enhance or enable the enhancement of an aquatic ecosystem elsewhere that will fully compensate for the significant adverse impact on that protected fish population or aquatic ecosystem resulting from granting the application, and
   b) if, in the circumstances described in paragraph (a) (ii), the decision maker imposes implementation of the mitigation measures, and in the circumstances described in paragraph (a) (iii), the decision maker imposes implementation of the compensatory mitigation measures, as terms and conditions of the authorization or change approval or amended authorization or change approval, as applicable.
4) If the decision maker considers that there is a reasonable alternative source of water reasonably available to an applicant making an application referred to in subsection (1), the decision maker may refuse to grant the application.

Transition — groundwater licensing

140 (1)Despite section 6 (1) *[use of water]*, a person who, on the date section 6 comes into force, is diverting or using, including storing, water, other than as described in section 6 (4) *[use of water — excluded groundwater users]*, from an aquifer for a water use purpose may continue to divert, store and use water from that aquifer for that purpose as follows:

a) if the person applies for an authorization on or before the date that applies to the person by regulations under subsection (2) (c), until the date a decision is made on the application;
b))f the person fails to apply for an authorization on or before the date that applies to the person by regulations under subsection (2) (c), until that date.

2) Despite sections 12 *[application and decision maker initiative procedures]*, 13 *[objections to applications and decision maker initiatives]*, 14 *[powers respecting applications and decision maker initiatives]*, 17 *[sensitive stream mitigation]*, 18 *[quick licensing procedures]* and 22 *[precedence of rights]*, the Lieutenant Governor in Council may make regulations
   a) (a)establishing application procedures and requirements for persons described in subsection (1),

b) (b)establishing for the purposes of section 22 the method for determining the precedence date of an authorization issued to a person described in subsection (1) (a), and

c) (c)providing for the application of the provisions of Part 2 *[Licensing, Diversion and Use of Water]* to persons described in subsection (1) at different times for different areas, aquifers, water use purposes or quantities of water diverted.

3) Despite any effect on the precedence of the rights under authorizations in effect on the date a person is issued an authorization in accordance with regulations under this section, the method for determining the precedence date of an authorization for the purposes of subsection (2) may provide for the rights under the authorization to have precedence from the person's date of first use for a specified water use purpose of a specified amount of water from the aquifer.

4) On and after the date a regulation under subsection (2) (c) applies Part 2 to a person, the person is liable for the applicable fees, rentals or charges for the water diverted from the aquifer and used by the person as if an authorization were issued to the person on that date.

Water Sustainability Regulation

Part 7 — Transitional Provision

Transition — groundwater licensing

55 (1) A person to whom section 140 (1) of the Act applies must apply on or before March 1, 2022 for an authorization authorizing the person's diversion and use of water from an aquifer.

2) Subject to this section, the Act and the regulations apply in relation to an application under subsection (1).

3) Despite section 12 (1) (b) (ii) *[application and decision maker initiative procedures]* of the Act, if an application under subsection (1) of this section is received on or before March 1, 2022, the applicant is exempt from the requirement to pay an application fee.

4) Applications under subsection (1) are exempt from section 15 (1) *[environmental flow needs]* of the Act.

5) For the purposes of section 22 (1) *[precedence of rights]* of the Act, the date set out in an authorization issued in relation to an application under subsection (1) of this section is to be the person's date of first use in relation to the diversion and use of water from the aquifer.

[am. B.C. Regs. 94/2016, s. 5; 301/2016, s. (a); 238/2017, Sch. A, s. 1 (b); 27/2019, s. (b).]

APPENDIX E

Unprecedented continental drying, shrinking freshwater availability, and increasing land contributions to sea level rise. Hrishikesh A. Chandanpurkar, James S. Famiglietti, Kaushik Gopalan, David N. Wiese, Yoshihide Wada, Kaoru Kakinuma, John T. Reager, Fan Zhang. Science Advances Research Article Climatology. July 25, 2025.

CLIMATOLOGY

Unprecedented continental drying, shrinking freshwater availability, and increasing land contributions to sea level rise

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Changes in terrestrial water storage (TWS) are a critical indicator of freshwater availability. We use NASA GRACE/GRACE-FO data to show that the continents have undergone unprecedented TWS loss since 2002. Areas experiencing drying increased by twice the size of California annually, creating "mega-drying" regions across the Northern Hemisphere. While most of the world's dry/wet areas continue to get drier/wetter, dry areas are now drying faster than wet areas are wetting. Changes in TWS are driven by high-latitude water losses, intense Central American/European droughts, and groundwater depletion, which accounts for 68% of TWS loss over non-glaciated continental regions. "Continental drying" is having profound global impacts. Since 2002, 75% of the population lives in 101 countries that have been losing freshwater water. Furthermore, the continents now contribute more freshwater to sea level rise than the ice sheets, and drying regions now contribute more than land glaciers and ice caps. Urgent action is required to prepare for the major impacts of results presented.

INTRODUCTION

Climate change is driving profound changes within the Earth system, including to its water cycle. While global temperatures continue to reach record heights (*1*–*3*), with the year 2024 being the hottest year in the past 175 years (*4*), the planet is experiencing increasing extremes of flooding and drought (*5*), widespread glacial and ice sheet melt and sea level rise (*6*–*8*), and greater risk of wildfire (*9*) and biodiversity loss (*10*).

As global patterns of precipitation, evaporation, and streamflow change (*11*), terrestrial water storage (TWS; all of the ice, snow, surface water, canopy water, soil moisture, and groundwater stored on land) has been shifting rapidly in response (*12*–*15*). Shifting patterns of TWS threaten water availability and sustainable water management for people and the environment, putting livelihoods and food security at risk (*16*) while acting as a trigger for climate migration (*17*) and transboundary conflict (*18*) both intra- and internationally.

As the dry areas of the world become drier (*13*, *16*, *19*) and surface water storage in rivers and lakes declines (*12*), society is becoming more reliant on groundwater (*20*). This increased reliance has led to its long-term depletion (*21*, *22*), which is exacerbated by global shortcomings in groundwater management (*20*, *23*) and which amplifies rates of TWS loss through a positive feedback. The consequences of global groundwater depletion include reduced irrigation water supply and threats to agricultural productivity, reduced capacity for climate adaptation, drought resilience and for growth in desert cities, reduced biodiversity (*24*) and damage to groundwater dependent ecosystems (*25*), decreasing access as water tables fall, and many others (*21*, *26*, *27*).

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Global TWS changes also have major consequences for interannual variations in sea level and long-term global mean sea level (GMSL) rise (*28*–*30*). The loss of freshwater from the continents and the ice sheets eventually leads to a corresponding increase in ocean water mass. While the continental contribution drives GMSL variations at seasonal and interannual timescales (*28*), its long-term contribution at longer timescales has, until recently (*8*), been smaller than the ice sheets on human timescales. If the TWS trends identified here continue, then this may never again be the case.

Here, we use more than two decades of observations (April 2002 to April 2024) from NASA's Gravity Recovery and Climate Experiment (GRACE) and GRACE Follow-On (GRACE-FO) missions (hereafter, GRACE/FO) (*31*, *32*) to evaluate how and why TWS has changed since 2002. We find that the continents (all land excluding Greenland and Antarctica) have undergone unprecedented rates of drying and that the continental areas experiencing drying are increasing by about twice the size of the State of California each year. The rapid expansion of dry areas has resulted in the emergence of "mega-drying" regions by interlinking of previously known drying hot spots (*13*), particularly since the strongest recorded El Niño of 2014 and across the Northern Hemisphere.

We find that, while most of the world's dry areas continue to get drier and its wet areas continue to get wetter, dry areas are drying at a faster rate than wet areas are wetting. At the same time, the area experiencing drying has increased, while the area experiencing wetting has decreased. We show that changes in TWS since previous global studies (*13*, *19*) are robust and are driven primarily by high-latitude water losses in Canada and Russia (most likely due to ice and permafrost melt), by the extreme Central American and European droughts of the past several years (*33*), and by continued global groundwater depletion (*13*, *14*, *21*, *22*), which accounts for 68% of the TWS trend over the non-glaciated continents.

We refer to the phenomenon of global-scale reduction in TWS as measured by the GRACE/FO missions as "continental drying." Our definition of continental drying implicitly includes melting of glaciers and ice caps (GICs) on land (distinct from the Greenland and

Antarctic ice sheets, see fig. S1). However, the expansion of drying regions reported here occurs in the non-glaciated regions. We take care to differentiate in the analyses below.

Here, we explore current rates of continental drying and its regional contributors, we discuss the implications of our findings by demonstrating their impact on freshwater availability and sea level rise, and we attempt to attribute its causes to human water management practices (e.g., overpumping groundwater) and/or to changing climate to help support evidence-based policy and decision-making.

We note that this continental drying affects most of the population and countries in the world. Roughly 75% of the global population lives in the 101 countries that have been losing freshwater water since 2002. Within the global water budget, the continents are now contributing more freshwater to sea level rise than the individual ice sheets. Furthermore, the drying regions on the continents now contribute more to sea level rise than GICs on land. Without urgent attention and action, the findings presented here may well continue to worsen, leading to accelerations in water insecurity (*20*, *23*, *26*, *27*) and sea level rise (*29*, *30*, *34*).

RESULTS

The emergence of mega-drying regions on the continents

Previous studies have documented regional and global patterns of TWS change (*13*, *14*, *19*) like those shown in the bias-corrected (i.e., downscaled) GRACE/FO trend map (see Materials and Methods) in Fig. 1B. These studies have identified the key features of TWS change on the continents, including high- and low-latitude wet areas getting wetter (WW) and mid-latitude dry areas getting drier (DD) as anticipated from climate change modeling studies (*35*), glacier and ice cap melting (*7*), global-scale groundwater depletion (*13*, *14*), and changing extremes of flooding and drought (*5*). Here, we show how recent changes in these regional and continental-scale TWS trend patterns are contributing to the increasing rates of continental drying reported in this study.

A critical, major development has been the interconnection of several regional drying patterns and previously identified hot spots for TWS loss to form four continental-scale mega-drying regions, all located in the Northern Hemisphere (shown with solid black outlines in Fig. 1B). These include (i) large swaths of northern Canada and (ii) northern Russia, where high-latitude wetting has now transitioned to drying; (iii) the contiguous region of southwestern North America and Central America, where aridification and groundwater depletion continue or are worsening; and (iv) the massive, tri-continental region spanning from North Africa to Europe, through the Middle East and Central Asia, to northern China and South and Southeast Asia, which owes its expansion to the recent European drought (*33*).

These changes, along with the more recent pronounced wetting of East Africa and western Sub-Saharan Africa, underpin the finding of expanding drying continental regions and shrinking wetting regions reported here. They are also reflected in the zonal plot in Fig. 1B. Except for the tropics between 10°S and 20°N, all latitudes now show a net negative TWS trend, even when excluding continental GICs. This result deviates from past studies (*13*, *19*) that documented first TWS observations of "wet getting wetter, dry getting dryer" (WW-DD), showing an increasing TWS trend in the Northern high latitudes. All trends discussed in this study are summarized in Tables 1 to 3 and table S1. As discussed below, we find that the trends reported here are robust and, therefore, unlikely to change, rather than emerging, as in previous studies [e.g., (*13*)].

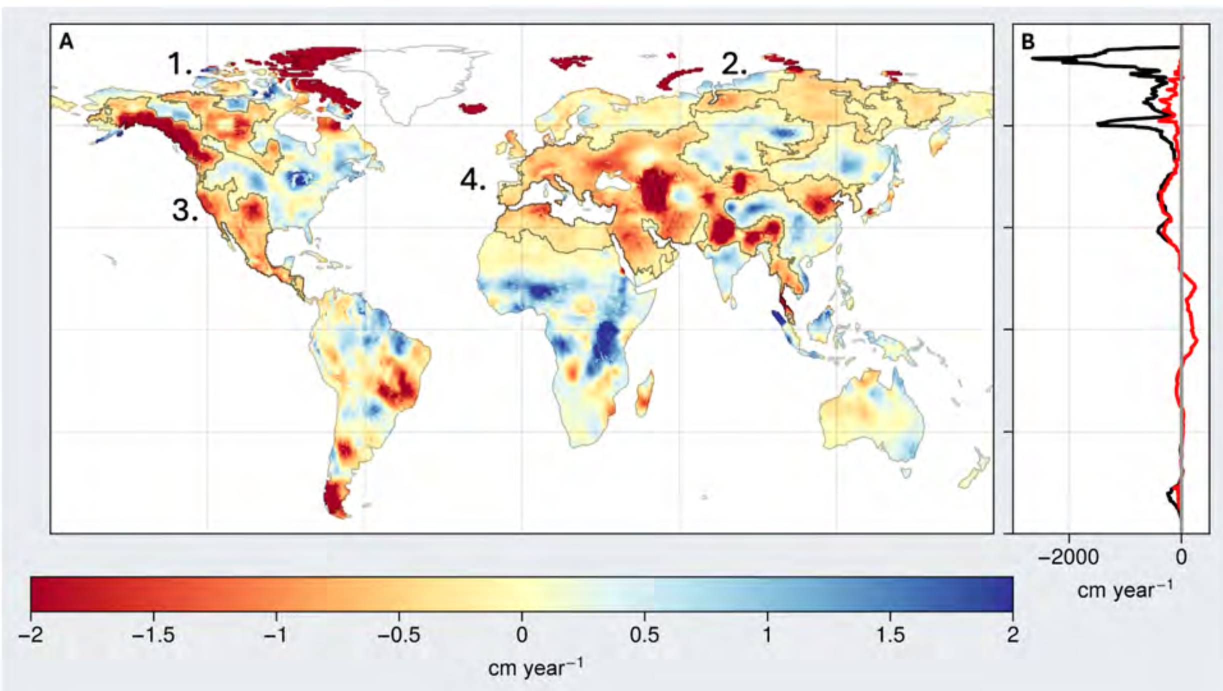

Fig. 1. Global map of long-term TWS trends from GRACE/FO. (**A**) Trends in TWS (cm year^{-1}) from February 2003 to April 2024 (see Materials and Methods). Mega-regions (regions exceeding −0.2 cm year^{-1} and connecting previously reported TWS hot spots) are outlined in black and labeled 1 to 4 corresponding to the main text. (**B**) Zonal sum of TWS trends for all (black) and non-glaciated regions (red).

Table 1. Long-term TWS trends in mega-drying regions from GRACE/FO. Trends (cm year^{-1}) are from February 2003 to April 2024 and are given with and without continental GICs when they are present. Uncertainties represent 90% confidence intervals on the trend estimation. AZ, Arizona; CA, California; CO, Colorado; KS, Kansas; NM, New Mexico; NV, Nevada; OK, Oklahoma; TX, Texas; UT, Utah.

Mega-drying regions	TWS trend in cm year^{-1}
Northern Canada and Alaska	−0.86 ± 0.03
Northern Canada and Alaska with GICs	−2.23 ± 0.05
Northern Russia	−0.41 ± 0.03
Northern Russia with GICs	−0.42 ± 0.03
Southwestern North America and Central America	−0.76 ± 0.04
Southwestern US states (AZ, CA, CO, KS, NM, NV, OK, TX, and UT combined)	−0.85 ± 0.05
Mexico and Central America combined	−0.66 ± 0.05
MENA and Pan-Eurasia	−0.83 ± 0.02
MENA and Pan-Eurasia with GICs	−0.88 ± 0.02
Northwest Sahara Aquifer System	−0.45 ± 0.01
Arabian Aquifer System	−0.64 ± 0.01
Caspian and Aral Seas	−3.0 ± 0.12
Tarim Basin	−0.39 ± 0.01
Tarim Basin with GICs	−0.52 ± 0.02
Indus Basin	−1.23 ± 0.07
Ganges-Brahmaputra Basin	−1.09 ± 0.09
Ganges-Brahmaputra Basin with GICs	−1.4 ± 0.09
North China Aquifer System	−0.82 ± 0.1
Myanmar	−0.37 ± 0.09
Thailand	−0.94 ± 0.1
Cambodia	−0.54 ± 0.13
Malaysia	−0.6 ± 0.06

Table 2. Rates of expansion of areas experiencing drying and wetting, including extremes. The rates are for the period from February 2004 to April 2024 unless noted otherwise. Both areas with and without GICs are mentioned. Uncertainties represent 90% confidence intervals on trend estimation.

Areas under drying	km^2 year^{-1}
Total land areas under dry anomalies	831,600 ± 69,100
Total land areas excluding GICs under dry anomalies	601,500 ± 65,200
Total land areas under dry extremes	845,065 ± 122,661
Total land areas excluding GICs under dry extremes	685,096 ± 110,021
Total land areas excluding GICs under dry extremes (February 2002 to December 2013)	−706,800 ± 156,500
Total land areas excluding GICs under dry extremes (January 2014 to April 2024)	2,610,000 ± 242,900
Areas under wetting	**km^2 year^{-1}**
Total land areas under wet anomalies	−831,600 ± 69,100
Total land areas excluding GICs under wet anomalies	−601,500 ± 65,200
Total land areas under wet extremes	−232,300 ± 128,800
Total land areas excluding GICs under wet extremes	−113,700 ± 117,000
Total land areas excluding GICs under wet extremes (February 2002 to December 2013)	−1,847,100 ± 226,600
Total land areas excluding GICs under wet extremes (January 2014 to April 2024)	1,650,900 ± 127,200

Table 3. Contributions to sea level rise from major global water reservoirs. Trend in mm SLE year^{-1} and Gt year^{-1} or km^3 year^{-1}. Includes decomposition of non-glaciated TWS into drying and wetting regions. Positive trends increase sea level and negative trends decrease sea level.

Global water reservoirs	Trend values (mm SLE year^{-1})	Trend values (Gt or km^3 year^{-1})
Global ocean	1.99 ± 0.2	724 ± 69
Greenland	0.73 ± 0.07	266 ± 25
Antarctica	0.37 ± 0.05	135 ± 19
Global land (TWS)	0.89 ± 0.15	324 ± 55
GICs	0.67 ± 0.04	243 ± 14
Non-glaciated TWS	0.22 ± 0.14	81 ± 52
Drying regions		
Non-glaciated TWS drying regions	1.01 ± 0.11	368 ± 40
Robust drying regions	1.29 ± 0.1	467 ± 37
Non-glaciated robust drying regions	0.7 ± 0.12	260 ± 43
Wetting regions		
Non-glaciated TWS wetting regions	−0.79 ± 0.12	−287 ± 44
Robust wetting regions	−0.44 ± 0.11	−161 ± 41
Non-glaciated robust wetting regions	−0.43 ± 0.11	−153 ± 41

Are high-latitude wet areas still getting wetter?
While glaciers melting in coastal Alaska and coastal western Canada and ice cap melting in the Canadian Archipelagos have long contributed to high-latitude TWS decline (*8*, *36*, *37*), the remaining non-glaciated high-latitude continents had been mostly increasing in TWS, largely driven by WW (*13*, *19*). However, as high latitudes warm at four times the global average rate (*38*), interior western Canada is now losing TWS likely due to drying of subarctic lakes (*12*), the Canadian prairies have experienced persistent drought for the past several years (*39*), and TWS is declining in northern Russia due to changes in precipitation and potentially due to changes in permafrost (*40*, *41*). Excluding GIC, the northern Canada mega-region TWS trend is −0.86 ± 0.03 cm year^{-1}, and the northern Russia trend is −0.41 ± 0.03 cm year^{-1}. Widespread but more dispersed drying is also seen across northern Europe/Scandinavia. While the atmospheric mechanisms of WW-DD are not disputed, it is possible that Coupled Model Intercomparison Project (CMIP) models (*42*, *43*) do not adequately represent ice, snow, and permafrost melt and declining surface water storage and, hence, cannot capture the emerging dynamics of TWS drying at high latitudes.

Southwestern North America and Central America
Several studies have focused on hot spots for decreasing TWS in the southwestern quadrant of the United States (−0.85 ± 0.05 cm year^{-1}), especially due to groundwater depletion in California's Central Valley (*44*–*46*) and the southern Ogallala Aquifer of the US High Plains (*45*), aridification (*47*), and groundwater depletion in the Colorado River basin (*48*, *49*). In contrast to earlier reports (*13*, *50*) that showed near-zero or wetting TWS trends in Mexico and Central America, we show here that they are undergoing recent and rapid TWS decline (−0.66 ± 0.05 cm year^{-1}). Furthermore, its extent now links together with California, the lower Colorado River basin, and the southern High Plains to create one large southwestern North American–Central American mega-drying region. This region includes the well-documented areas for groundwater depletion noted above, as well as in Mexico City (*51*), that are all exacerbated by DD and ongoing drought (*33*). The rate of declining TWS across the entire mega-region is −0.76 ± 0.04 cm year^{-1}.

Middle East/North Africa–Pan-Eurasia
The outline in Fig. 1B shows the tremendous extent of this mega-drying region, which is losing TWS at the rate of −0.88 ± 0.02 cm year^{-1}. The region is dominated by DD, which places even more stress on its dwindling groundwater resources. In contrast to earlier findings (*13*, *19*), this study finds a recent pronounced decline in TWS across much of Europe, consistent with the recent catastrophic drought events that were found to be influenced by climate change and are among the worst in the past 2000 years (*52*). The drying now includes the British Isles and all the countries in Western and Eastern Europe. North Africa almost entirely shows a decline due to DD (*3*, *52*), as well as from considerable groundwater depletion in the North-Western Sahara Aquifer System shared by Algeria, Libya, and Tunisia (*14*, *53*).

Pronounced drying across the Middle East through DD and groundwater depletion has been well-documented (*14*, *54*, *55*) and continues to be among the most severe in the world. Here, we highlight trends in this mega-region that have been relatively underreported in the literature. For example, the Arabian Aquifer System (*56*, *57*) is losing TWS at a rate of 0.64 ± 0.01 cm year $^{-1}$. Central Asia is rapidly losing TWS through DD and groundwater depletion, particularly around the Caspian and Aral seas, where agriculture and cotton production rely heavily on groundwater (*58*, *59*). TWS losses in the combined Caspian (*60*) and Aral Seas are −3.0 ± 0.12 cm year^{-1}.

Groundwater depletion continues unabated in the agricultural regions on the perimeter of the Tibetan Plateau. Excluding GIC, TWS losses in the Tarim Basin are −0.39 ± 0.01 cm year^{-1}, in the Indus Basin are −1.23 ± 0.07 cm year^{-1}, and in Ganges-Brahmaputra Basin (*61*) are −1.09 ± 0.09 cm year^{-1} [which are consistent/worse than previous reports (*12*, *13*, *61*–*63*)]. The extent of the tri-continental drying region now links to the North China Aquifer System (*64*) to the east, where groundwater depletion is driving TWS declines to −0.82 ± 0.1 cm year^{-1}, and to Southeast Asia, where DD is now responsible for declines in Myanmar (−0.37 ± 0.09 cm year^{-1}), Thailand (−0.94 ±

0.1 cm year^{-1}), Cambodia (-0.54 ± 0.13 cm year^{-1}), and Malaysia (-0.6 ± 0.06 cm year^{-1}).

Increase in the land areas under drying and dry extremes

The emergence of interconnected mega-drying regions is coincident with the increase in area on the continents showing monthly dry anomalies. The rate of increase of drying areas is 831,600 ± 69,100 km^2 year^{-1}, which is roughly equivalent to twice the size of the State of California annually. The area experiencing dry extremes (defined here as dry anomalies that are greater than 1-sigma, see Material and Methods) also grew by a similar rate of 845,000 ± 122,600 km^2 year^{-1}. These increases are largely driven by drying in the non-glaciated regions (Fig. 2), where the area under dry anomalies increased by 601,500 ± 65,200 km^2 year^{-1} and area under dry extremes increased by 685,100 ± 110,000 km^2 year^{-1}.

Since 2014, the year of onset of the strongest El Niño on record, the total non-glaciated area experiencing extreme drying began increasing rapidly, by 2,610,000 ± 242,900 km^2 year^{-1}. This is despite the fact that recent years have been dominated by La Niña events (blue background in Fig. 2) and that La Niña events typically result in above average TWS (*29*, *30*).

Complementing the increased drying, both the area that is getting wetter and the area that is experiencing wet extremes have decreased (Fig. 2). The wet areas decreased by −831,600 ± 69,100 km^2 year^{-1} (and by 601,500 ± 65,200 km^2 year^{-1} over non-glaciated land). These values are the inverse of areas under drying, see Material and Methods), while the area experiencing wet extremes decreased by −232,300 ± 128,800 km^2 year^{-1}. However, as in the case of the drying extremes, growth in the area experiencing wet extremes begins increasing around 2014, but at a slower rate (1,650,900 ± 127,200 km^2 year^{-1} over non-glaciated land) than that of the areas experiencing dry extremes.

Figure 3 shows how the dry and wet extremes have changed in location and existence in the past 20 years, in successive 5-year periods (May 2004 to April 2009, May 2009 to April 2014, May 2014 to April 2019, and May 2019 to April 2024). Specifically, Fig. 3A shows how the percentage of months experiencing extreme drying decreases through April 2014 and then begins increasing in May 2014 (see figs. S2 and S3 for yearly maps of the number of months each year of extreme drying/extreme wetting anomalies). The final 5-year period shows a marked increase in the percentage of months under dry extremes, that the spatial distribution of the affected regions closely corresponds with the shapes of the mega-drying regions discussed above, and a shift from most dry extremes occurring in the southern hemisphere to most occurring in the Northern Hemisphere and for a longer duration. Hence, it is clear that increasing extremes of drought, in both areas, location and duration, are driving the growth of previously identified hot spots or drying regions, into interconnected, continental-scale mega-drying regions, particularly in the Northern Hemisphere.

The corresponding changes in extreme wetting area are shown in Fig. 3B. As above, they complement the changes in extreme drying area, in both timing and in location, from predominantly occurring in the Northern Hemisphere before May 2014 to predominantly in the southern hemisphere by the past 5-year period.

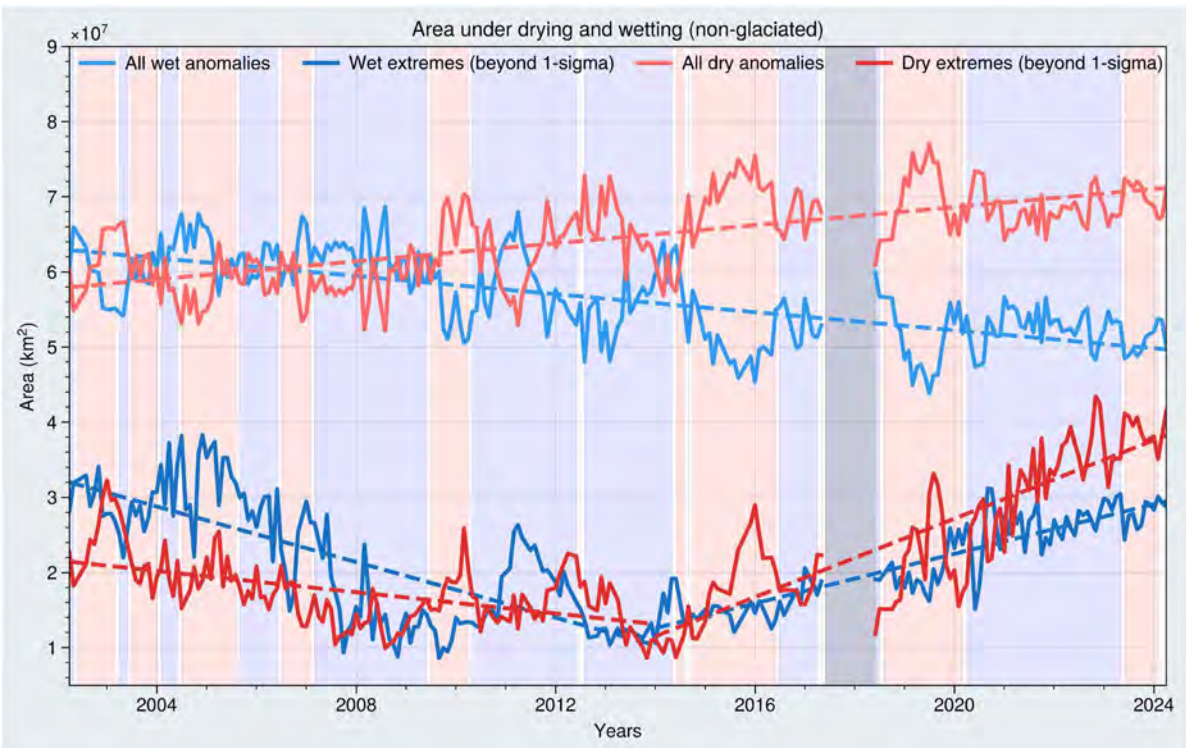

Fig. 2. Changes in areas experiencing wet and dry conditions, including extremes. Changes in the global non-glaciated area under dry (light red) and wet (light blue) anomalies (monthly deviations from monthly climatology) and under dry (dark red) and wet (dark blue) extremes (monthly anomalies that are greater than 1 SD at each location). Positive (La Niña) and negative (El Niño) ENSO events shown as blue and red background color, respectively. Vertical gray bar represents gap between GRACE and GRACE-FO.

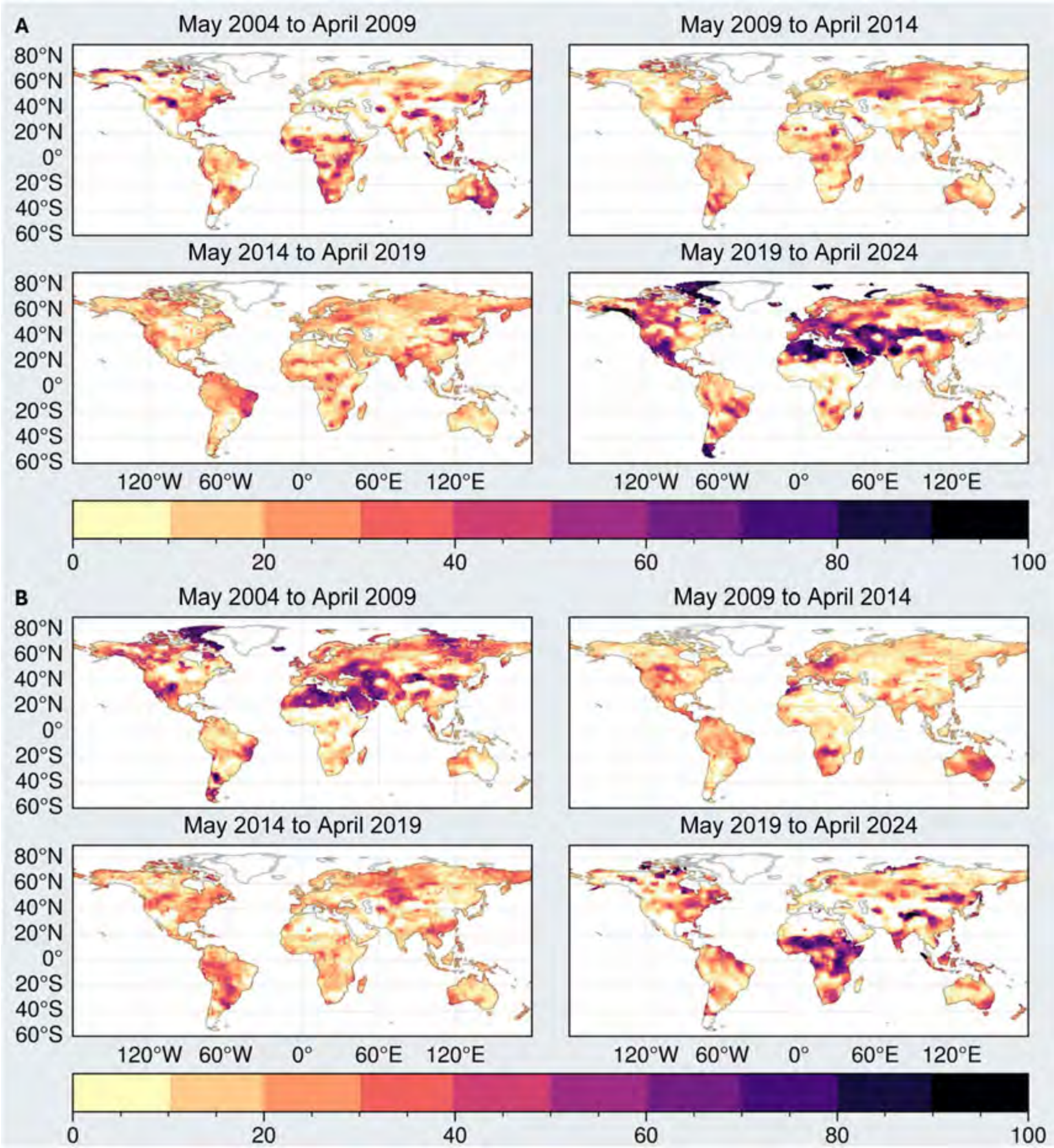

Fig. 3. Mapping location and presence of dry and wet extremes. (**A**) Percent of months in successive 5-year periods for which a region experienced dry extremes. (**B**) As in (A) but for extreme wetting. "Extremes" here are defined as monthly TWS anomalies at each location that are greater than 1-sigma (1 SD of the local deseasonalized TWS).

To our knowledge, this hemispheric oscillation in TWS has not been documented. It may well be tied to longer-term oscillations like the Pacific Decadal Oscillation (PDO). Previous research suggests the PDO has a greater influence on TWS distributions than El Niño–Southern Oscillation (ENSO) at decadal timescales (*65–67*).

Robustness of trends and implications for shrinking freshwater availability

Here, we discuss the spatial trends in terms of their robustness and long-term persistence relative to interannual variability. The regions highlighted in Fig. 4A are those where the sign of the local trends has remained the same for more than 90% of iterations of increasing GRACE/FO record length (see Materials and Methods). These regions show reduced sensitivity to the increasing data records, i.e., they have been showing reliable long-term trends for the past 22 years, which arguably can be expected to persist in near future.

An important finding is that most of the drying regions discussed in the previous section show little sensitivity to a lengthening GRACE/FO record. In other words, their drying is robust. These include most of the continental GIC regions (e.g., Alaska, the Canadian Archipelago, and Patagonia), much of the Middle East/North Africa (MENA)/Pan-Eurasia mega-drying region, the high-latitude Canada and northern Eurasia mega-drying regions, and several of the world's major aquifer systems discussed above and listed in Table 1 and table S1 and shown in fig. S4 (e.g., California's Central Valley; southern Ogallala Aquifer; Northwestern Sahara Aquifer System; Arabian Aquifer System; the Tarim, Indus, and Ganges-Brahmaputra Basins; and North

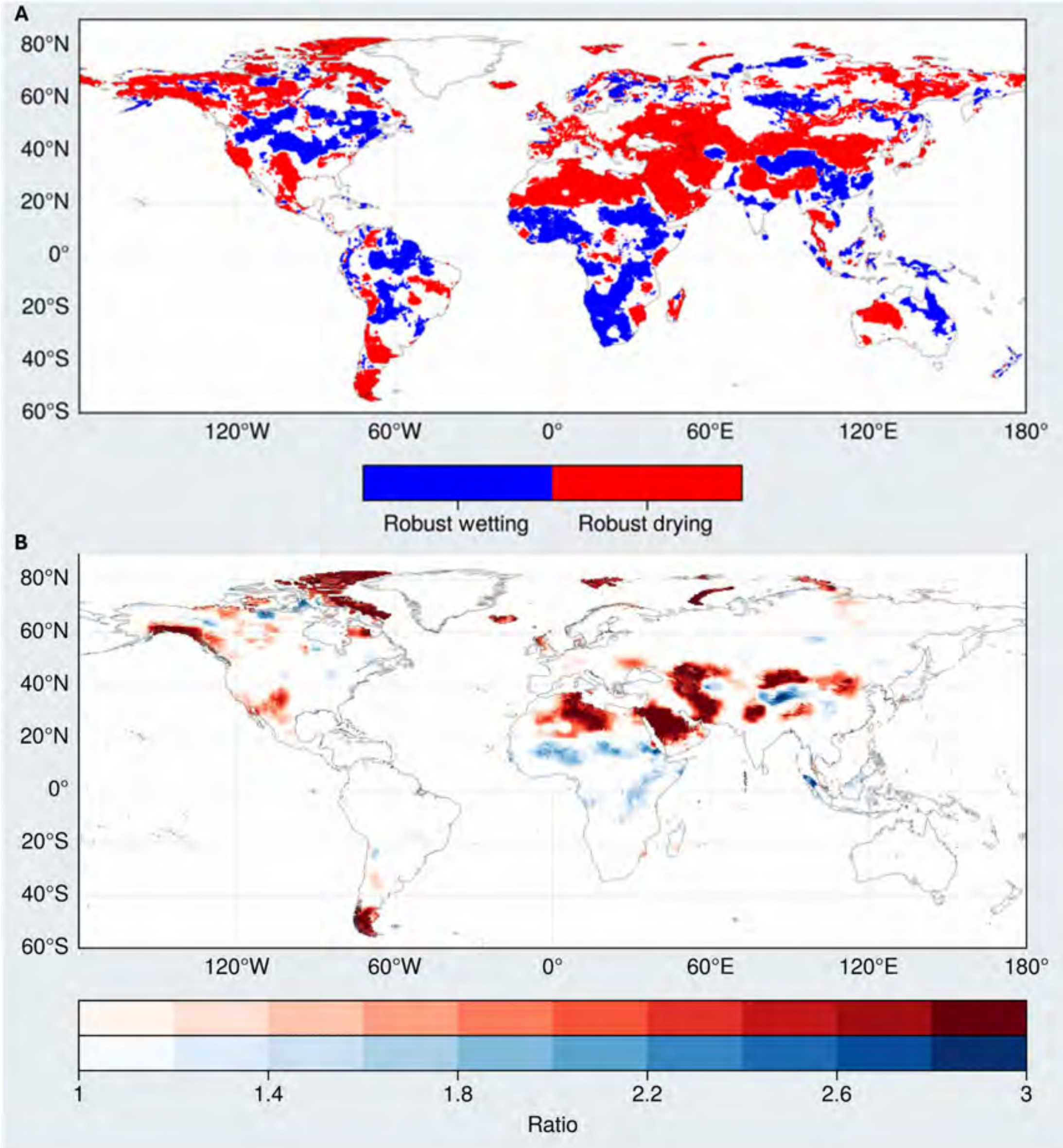

Fig. 4. Mapping robustness of TWS trends. (**A**) Drying and wetting land regions from Fig. 1B where the TWS trend sign has been persistent and less sensitive to the increasing GRACE/FO record length. (**B**) Ratio of local interannual variability of detrended TWS anomalies to their long-term local trends. The red and blue color bars indicate regions with decreasing TWS trend and increasing TWS trend from Fig. 1B, respectively.

China Aquifer System). On the other hand, most of the tropical wetting regions (e.g., eastern Brazil, Sub-Saharan and Rift Valley Africa, central India, Indonesia, and the South Pacific Islands of Oceana) also show little sensitivity, as do pockets of high-latitude wetting on all the continents. However, the majority of the area under persistent trends is drying (62%).

Further insight into the relative importance of the long-term trends compared to interannual variability is provided in Fig. 4B. The values represent the ratio between long-term variance and the interannual variance. Long-term variance is represented as the SD of the linear fit to the long-term trend, and the interannual variance is represented as the SD of the TWS anomalies after removing the long-term trend. A ratio greater than 1 indicates that the variance from the long-term trend is at least as big as that from the interannual variability. In line with the findings of the above sensitivity test, an overwhelming number of locations (73%) where the long-term variance is more than interannual variance are in the drying regions and have long-term variance to interannual variance ratio as high as 5.8.

In contrast, trends in several locations that show prominent wetting in Fig. 4B, such as in eastern North America, northeastern South America, southern Africa, and eastern Australia, are less than the interannual variability experienced by these regions. While some of these also show up as robust in the above sensitivity test, they have been dominated by some pronounced wet extreme events (*29*, *65*, *66*) and, consequently, their persistence is uncertain.

The locations where the spatial TWS trends are persistent and where the long-term variance exceeds the interannual variance are best understood in the context of their geography and characteristics. Land GICs are anchored in space and are continuously melting in response to rising temperatures. The progression of some of the high-latitude regions from WW to drying reflects the rapidly warming environment and the long-term melting of ice and permafrost and which contribute to the disappearance of subarctic lakes. Groundwater aquifers are fixed locations that are being heavily exploited for irrigated agriculture. Mid-latitude DD regions already have low annual rainfall totals that are expected to decrease, while evapotranspiration rates are increasing. In the absence of major climate change and water management interventions, these drying TWS trends are expected to continue. Likewise, tropical regions have a strong relationship to ENSO and other climate variability modes, have a pronounced annual cycle, and are wet regions to begin with. While some of these might follow the long-term WW phenomena, the dominance of interannual variability along with the modulation of the pronounced seasonal cycle (*28*, *65*–*67*) is likely to continue.

Shrinking freshwater availability

The implications of continental drying for freshwater availability are potentially staggering. Nearly 6 billion people, roughly 75% of world's population in 2020, live in the 101 countries that have been losing freshwater over the past 22 years (Fig. 5). Key contributors to the expansion of drying regions, declining TWS, and shrinking freshwater supply include melting GICs, the increasing severity of drought, the decreasing surface water availability, and groundwater depletion and all are continuing. Recent studies estimate that up to 83% of world's glaciers will likely melt out over the next 80 years (*68*); that the severity of drought has worsened in the past 5 years (*4*, *5*, *30*, *33*, *52*); that surface water storage in rivers, lakes, and reservoirs is in decline (*11*); and that half of the world's major aquifers are being rapidly depleted (*13*, *14*, *26*, *27*, *50*).

To assess the importance of TWS trends at the local level, we compared the TWS trends with annual renewable freshwater for level 5 HydroBASINS (*69*). The annual renewable freshwater is defined as precipitation minus evapotranspiration minus the environmental flow requirement (*70*). As illustrated in fig. S5, the median long-term TWS trend magnitude is about 3% of annual freshwater supply for all basins, 5% for the basins that are drying, and 2% for the basins that are wetting. The importance of the median TWS trend increases for basins that are arid (8%) and basins that are arid and experiencing drying (10%). The basins highlighted in red indicate regions where water losses and demands have persistently outpaced renewable supply, making it increasingly difficult to offset water storage deficits (*14*).

We used a global hydrological model [WaterGAP2.2d (*71*); see Materials and Methods] to show that the largest single contributor (68%) to the TWS loss on the non-GIC drying continental areas comes from groundwater (*29*), followed by surface water (18%), soil moisture (9%), and snow water equivalent (5%) (see figs. S1 and S6). Given these current trajectories, rates of continental drying are on track to continue or increase in the coming decades, and, consequently, freshwater availability will continue its current or accelerated decline.

Contributions to sea level rise

We present the latest GRACE/FO water mass anomaly time series for the global ocean, the Greenland and Antarctic ice sheets, and the continents (Fig. 6A), including their secular trends over the 22 years of GRACE/FO observations (Fig. 6B, left), also summarized in Table 3. Note that, in Fig. 6 and Table 3, decreasing (drying) trends in TWS are positive contributions to GMSL, and increasing (wetting) trends in TWS are negative contributions to GMSL. Global ocean mass continues to increase at a rate of 1.99 ± 0.2 mm Sea Level Equivalent (SLE) year^{-1}. Figure 6A shows that, since 2015, it is being driven primarily by decreasing TWS (0.89 ± 0.15 mm SLE year^{-1}), rather than by the melting of the Greenland (0.73 ± 0.07 mm SLE year^{-1}) and Antarctic (0.37 ± 0.05 mm SLE year^{-1}) ice sheets. In other words, the continents are now the leading contributor (44%) to mass-driven GMSL rise, while Greenland and Antarctica contribute ~37 and ~19% respectively.

To better understand the dynamics of continental drying and their contributions to GMSL, we decompose the continents into their drying and wetting components (Fig. 6B, right; see Materials and Methods

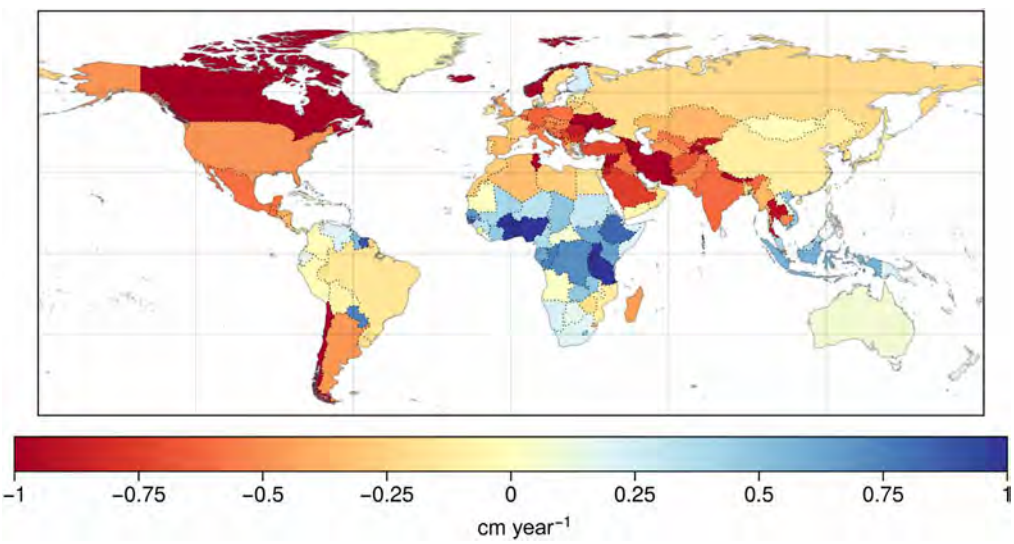

Fig. 5. Long-term mean TWS trends from GRACE/FO by country. TWS trends (February 2003 to April 2024) averaged for every country.

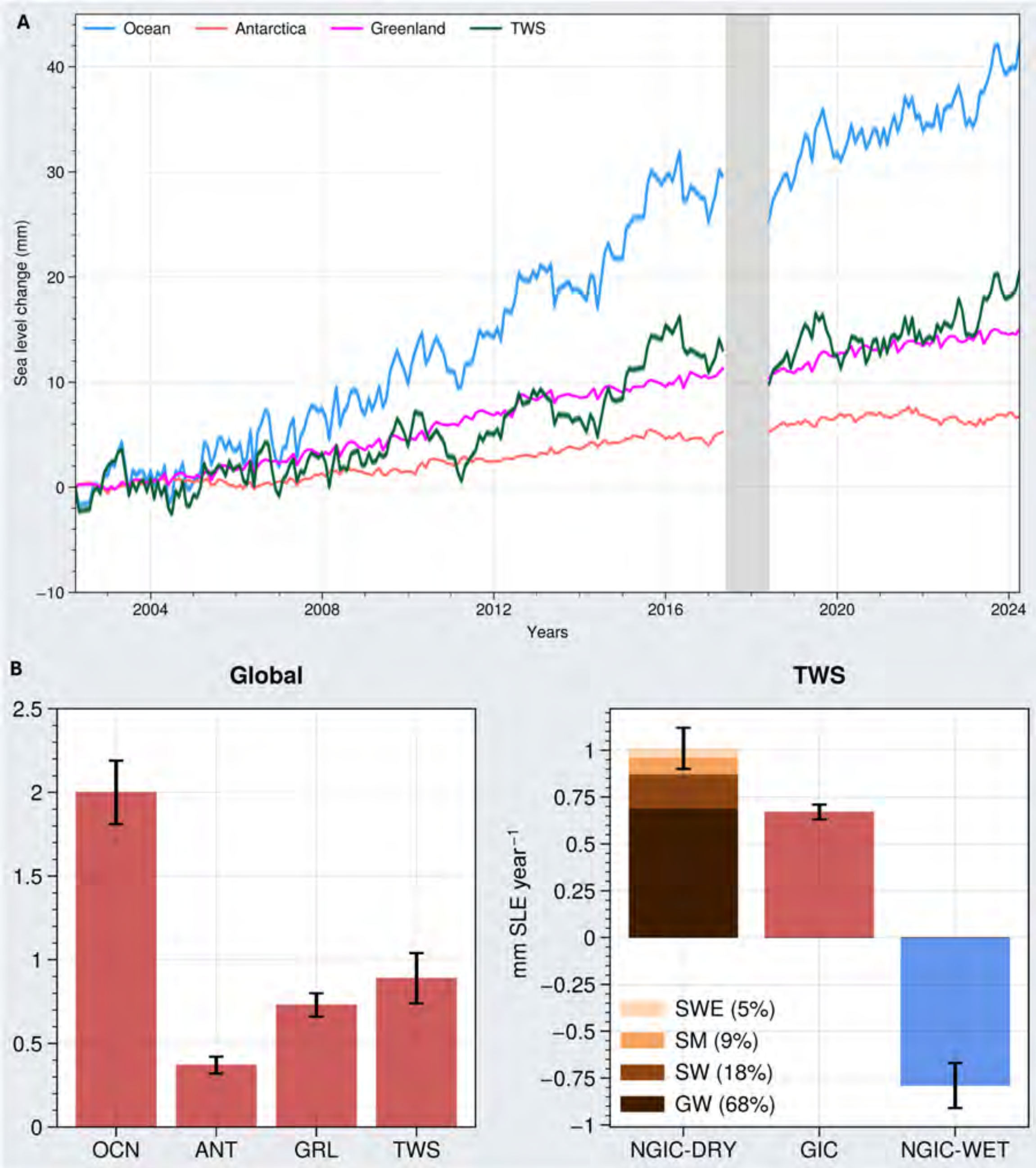

Fig. 6. Global water mass contributions to sea level rise. (**A**) Time series of water mass anomalies of the major global water reservoirs (Ocean, Antarctica, Greenland, and TWS on the continents) from GRACE/FO from April 2002 to April 2024, in mm SLE. (**B**) Left: Corresponding trends (in mm SLE year^{-1}) for the ocean (OCN), Antarctica (ANT), Greenland (GRL), and TWS time series in (A). Water mass contributions that increase sea level are shown as positive. Right: TWS trend decomposed into its non-glaciated drying (NGIC-DRY), glaciated drying (GIC), and non-glaciated wetting (NGIC-WET) components. NGIC-DRY is further decomposed into groundwater (GW), surface water (SW), soil moisture (SM), and snow water equivalent (SWE), on the basis of their contributions to the TWS trend. See also figs. S1 and S6.

and fig. S1) using the global map of TWS trends in Fig. 1B and the global hydrological model mentioned above (see also fig. S6). Consistent with earlier work (*19*), we find that pronounced drying signal (1.7 mm SLE year^{-1}) observed on the continents gets somewhat dampened by the wetting signal (−0.81 mm SLE year^{-1}) due to strong, climate-driven wetting trends in a few key regions mentioned previously.

However, in the drying regions, melting of land GICs (0.67 mm SLE year^{-1}), i.e., GIC, is no longer the leading continental contribution to GMSL rise. Rather, it is now outpaced by the combination of increasing drought and increasing groundwater depletion in the remainder of the drying regions of the continents (1.01 mm SLE year^{-1}; NGIC-DRY in Fig. 6B, right). As discussed above, changing extremes are an important contributor to the expansion of continental drying beyond the glaciated regions, and hence to rates of GMSL rise. However, most of these non-glaciated drying trends are robust (based on the trend persistence test illustrated in Fig. 4A), contributing 0.7 mm

SLE year^{-1} to GMSL, while having about 40% lower year-to-year variability compared to robust non-glaciated wetting regions (fig. S7, A and B).

DISCUSSION

The expansion of continental drying, the increase in extreme drying, and the implications for shrinking freshwater availability and sea level rise should be of paramount concern to the general public, to resource managers, and to decision-makers around the world. The robustness of the trends reported here, along with a critical shift in the behavior of TWS and continental drying following the major El Niño beginning in 2014, may well mean that reversing these trends is unlikely. Combined, they send perhaps the direst message on the impact of climate change to date. The continents are drying, freshwater availability is shrinking, and sea level rise is accelerating (*34*).

Implications for freshwater availability

At present, overpumping groundwater is the largest contributor to rates of TWS decline in drying regions, significantly amplifying the impacts of increasing temperature, aridification, and extreme drought events. However, groundwater depletion is most directly affected by, and can also be arrested by, water management decisions. The continued overuse of groundwater, which, in some regions like California, is occurring at an increasing, rather than at sustainable or decreasing rates (*46*), undermines regional and global water and food security in ways that are not fully acknowledged around the world.

In many places where groundwater is being depleted, it will not be replenished on human timescales. The disappearance of groundwater from the world's aquifers (*13*, *14*, *20*, *26*, *27*, *50*) is a critical, emerging threat to humanity and presents cascading risks that are rarely incorporated in environmental policy, management, and governance. It is an intergenerational resource that is being poorly managed, if managed at all (*20*, *26*, *50*), by recent generations, at tremendous and exceptionally undervalued cost to future generations. Protecting the world's groundwater supply is paramount in a warming world and on continents that we now know are drying.

Implications for sea level rise

The continents are now contributing more fresh water to GMSL rise than melting of the Greenland and Antarctic ice sheets. As the rate of continental drying and the intensity and frequency of extremes continue to increase, they may trigger unanticipated and frequent accelerations (*34*) in the rate of sea level rise that most coastal regions must better prepare for. Broader mitigation and adaptation strategies may involve storing more water on land or leaving more water in place, since increasing TWS would decrease rates of GMSL rise. Significantly slowing rates of global groundwater depletion, which, on its own, rivals GIC contributions (Fig. 6B, right), while facilitating large-scale groundwater recharge is, therefore, a global imperative, not only for preserving this precious resource for future generations but also for managing the global water balance to minimize groundwater depletion-driven freshwater inputs into the world oceans.

Call to action

While efforts to slow climate change may be sputtering (*72*, *73*), there is no reason why efforts to slow rates of continental drying should do the same. Key management decisions and new policies, especially toward regional and national groundwater sustainability, and international efforts, toward global groundwater sustainability, can help preserve this precious resource for generations to come. Simultaneously, such actions will slow rates of sea level rise.

We hope that the findings of this work will serve to raise awareness of the urgent, global need to prepare for shrinking freshwater availability on land; greater vulnerability to sea level rise along coastal regions; and the interconnected, widespread impacts of continental drying on people, the environment, and the economy. Major coordinated, national, international, and global, transdisciplinary efforts are critically needed to elevate the level of awareness and action around continental drying and decreasing freshwater availability to that of the carbon cycle.

MATERIALS AND METHODS

GRACE/FO data

JPL GRACE/ GRACE-FO Mascon Release 6 Version 3 (JPL-M) (*74*) data are used to represent TWS anomalies. While mascon solutions from other processing centers are also available, the choice to use JPL-M stems from the lesser spatial correlation between the individual mascons. JPL-provided 1-sigma formal uncertainties in JPL-M are included in the uncertainty quantification described below. Global analysis is performed at the native resolution (~3° resolution fields provided at 0.5° × 0.5° grid for better delineation of the land-ocean boundaries) for the period from April 2002 to April 2024. The gap months between GRACE and GRACE-FO are ignored in the analysis while sporadic gaps in data records are interpolated after removing the climatology following the methods in previous studies (*21*).

Trend and trend uncertainty computation

Long-term linear trends are computed by first removing the seasonal cycle by taking anomalies from the climatology and then applying an ordinary least-squares regression. Uncertainties on the trends aim to account for the uncertainty in GRACE JPL mascons and the uncertainty in the least-squares regression and are computed as follows: (i) Least-squares regression fit is computed along with the 90% confidence interval; (ii) the formal (1-sigma) uncertainty provided with the mascon product, which is unique to each mascon, is weighted by the area of that mascon within the region of interest. For example, if land covers only 25% of a mascon, then the error value for that mascon is multiplied by 0.25, and if the entire mascon is within land, then it is multiplied by 1. Then, root sum of squares for all the weighted error values is computed. These are the monthly uncertainties on the monthly TWS value for the region of interest; (iii) the average monthly formal (1-sigma) uncertainty is considered and applied as a positive uncertainty to the first half of the time series and as negative uncertainty to the second half of the time series, and vice versa. The trends computed from these provide the maximum and minimum regression values possible given the monthly formal uncertainty in data. The average difference from the regression fit with the min-max regression fits is considered as the uncertainty in long-term trends due to uncertainty in data; (iv) uncertainty obtained in step (iii) is added to the 90% confidence on the regression fit obtained in step (i). The total uncertainty, thus, is representative of the uncertainty in JPL mascons, as well as uncertainty in the regression model.

Resolution enhancement for regional trends

The global analysis is performed at the original resolution of JPL-M. However, when discussing finer-scale trends such as grid-scale (Fig. 1) or boundaries with differing geographies, such as countries (Fig. 5) or smaller watersheds (fig. S5), it is useful to be able to infer sub-mascon-scale TWS information. Hence, for regional analysis, we enhance the resolution of the JPL-M to 0.25° × 0.25°. This is performed by bias correcting the higher-resolution (0.25° × 0.25°) TWS estimates from NASA Global Land Data Assimilation System Version 2 (GLDAS-2.2-DA) (*74*). The GLDAS-2.2-DA product is chosen because it assimilates, among other observation records with Catchment Land Surface Model L4 (CLSM4) (*75*), the GRACE/FO observations of the TWS [specifically, the mascon solutions from Center for Space Research; (*76*)], and, hence, its TWS output is already closer to GRACE observations than conventional, non-assimilated models. Still, biases arise due to the limitations in the land surface models in representing the cryospheric processes, subsurface hydrology, and human activities; the uncertainties in the forcing data; and the uncertainties in the assimilation process. Hence, a bias correction is applied as follows: (i) We first upscale the GLDAS model grid to a 0.5° grid matching with the JPL-M grid; (ii) to correct for the above bias, we apply a bias correction to the model output such that it matches the observed data at mascon scale. Because the variability of the fluxes within the extent of a mascon is unknown, we apply a mean correction over the entire extent of the mascon, i.e., we traverse across every mascon, and, for each one, we calculate the cumulative difference between the model data for that mascon. This value is normalized by the total number of 0.5° grids within the mascon, and the normalized bias is applied over every grid contained in the mascon; (iii) the normalized biases are resampled to 0.25° resolution through first-order spline interpolation using a widely used Python library (skimage) (*77*). (iv) Additionally, the biases are smoothed spatially using a moving-average filter of 9 × 9 grids to reduce the signal discontinuities at the mascon boundaries. This smoothed bias is added to the GLDAS output to get the final output that is the GLDAS model bias corrected with GRACE observations. Thus, the output retains the variability of the GLDAS model while being essentially unbiased at a global level and minimally biased at a mascon level relative to the GRACE/FO JPL mascons. The resolution enhancement is demonstrated for long-term trends over California in fig. S8. The model data are available starting February 2003 instead of April 2002 of GRACE; hence, the regional trends described in this study typically cover the period from February 2003 to April 2024, while the global analysis covers the period from April 2002 to April 2024.

Identifying mega-drying regions

The mega-drying regions outlined in Fig. 1B were identified by grouping previously identified hot spots with interconnecting areas that have shown a change in trend from positive to negative, in particular since previous publications (*13*, *19*). Two criteria were used to define a mega-drying region: (i) a threshold value of -0.2 cm year^{-1}, which is the 30th percentile of all the local trend magnitudes, was used to bound the mega-drying regions; and (ii) only those regions beyond the threshold that contained two or more previously identified drying hot spots. The grouping is subjective but is informed by experimentation and by the literature and is meant to highlight that vast, continuous regions between the previously studied hot spots are also drying, albeit at a moderate rate, and hence are typically overlooked. The Southern Hemisphere is largely excluded when identifying mega-drying regions because the threshold conditions are not typically met and also because, as we highlight in Fig. 4B, the region is typically governed by strong interannual variability.

Robustness of trends

GRACE record is relatively short (~22 years against the recommended 30 or more) for climatological studies. The TWS trends over several regions, such as the Amazon, have flipped signs over the course of the GRACE mission. This begs the question, "How likely are the currently observed GRACE trends likely to persist?" To address this, we conduct a test for trend persistence by testing the sensitivity of the TWS trends to the increasing GRACE/FO record. As a starting step, local trends are computed for the first 5 years of the GRACE record. Then, the local trends are subsequently recomputed with addition of each successive month of GRACE/FO data. For example, the first iteration of local trend computation is from first 5 years of GRACE, and the past iteration of the trend computation is from the entire GRACE/FO record. This results in multiple (195) trend values for each location. The locations where the trend sign does not change for 95% of the instances are considered locations with robust drying or wetting trends and are shown in Fig. 4A. These are the locations where the trend signs did not change much (185 of the 195 instances), irrespective of when, during the GRACE record, the trends were assessed, and hence are likely to continue, unless the mechanisms governing the TWS trends change.

Separating ocean, ice sheets, GIC, wetting, and drying regions

Ocean and land mascons are separated using the ancillary land-ocean mask associated with the mascon data product. The GIC mask (fig. S1) isolates masons that predominantly show ice mass changes (>1% of area is covered by glacier/ice), consistent with what has been used in previous publications (*30*). To be conservative in our analysis, mascons that neighbor those with strong ice mass trends (mascon IDs 97, 215, 216, 217, 269, 441, 3995, and 4071) are additionally included in the GIC mask to capture any residual ice mass leakage signals that exist. The wetting and drying regions are separated on the basis of the sign of their above-described long-term trends (fig. S7).

Identifying and mapping growth of wetting and drying anomalies and extremes

To identify dry and wet anomalies, the TWS grids are first de-seasoned by subtracting the monthly climatology from each corresponding month to get deviations from the seasonal cycle, and the long-term mean is also removed in this process. Then, for each month, the locations where the anomalies are dry (and wet) are identified. The areas of those grids are computed and summed together to get total global area under wet and dry anomalies, and their trends are computed and provided in Table 2. Area under wet and dry anomalies is also computed after removing the GIC grids using the above-described mask. To identify wet and dry extremes, the local TWS data are first de-seasoned by removing the monthly climatology and then standardized by dividing them by their local SD. Any residual that is larger than a 1-sigma anomaly relative to climatology gets categorized as "extreme." In other words, the locations where the monthly anomalies are greater than 1 are considered wet extremes and less than 1 are considered dry extremes. The areas of these grids are computed and summed together and provided as areas under wet and dry extremes, both with and without glaciers, in Table 2. To compute the timing and presence of wet and dry extremes in Fig. 3, the above-described monthly grids with extreme values are chunked into 5-year periods, and, for each grid, the number of months in these 5 years (totaling 60 months) when the grid showed an extreme value is recorded and converted to a percentage. For figs. S2 and S3, instead of 5-year periods, the monthly grids are aggregated into yearly grids, and the same statistic is calculated.

Decomposing TWS into its SWE, surface water, soil moisture, and groundwater components

The trend is global non-glaciated TWS is further decomposed into TWS components groundwater, soil moisture, surface water, and snow water equivalent. For groundwater and soil moisture, GRACE-assimilated GLDAS-2.2-DA (the same model used for enhancing the resolution of TWS in the study) is used. Because surface water component is absent in GLDAS, it is obtained from WaterGAP 2.2d (*34*, *78*), which has been calibrated with observed river discharge and soil moisture worldwide, which generally yields much improved estimates of surface hydrological fluxes and storage compared to other global hydrological models. To avoid double counting of surface water, the equivalent value (SW_{WG}) is removed from the soil moisture component from GLDAS (SM_{GLDAS}). The SWE component from GLDAS showed a positive trend in the global SWE, which differed from most datasets. Hence, WaterGAP SWE was used instead. Thus, a new TWS is computed by adding the merged components

$$TWS_{merged} = GW_{GLDAS} + SW_{WG} + SWE_{WG} + SM$$

Here, $SM = \left(SM_{GLDAS} - SW_{WG}\right)$. Contribution of the trends in individual components to the merged TWS is computed after removing the glaciated regions. The TWS signal within the Caspian Sea perimeter, which is missing in the models, is obtained from GRACE and is attributed as surface water. We acknowledge that the model outputs have uncertainties due to the limited representation of hydrology and the choice of forcing datasets and attempt to reduce the uncertainties by choosing a model that's assimilated with GRACE for groundwater and soil moisture estimates and by choosing a model that's calibrated against river discharge for surface water storage estimates. To reduce the uncertainties and biases caused by differing heterogeneity in model and observations, we also limit the TWS decomposition to the (non-glaciated) global scale.

Annual renewable water

For the analysis illustrated in fig. S5, annual renewable water is considered as precipitation minus evapotranspiration minus environmental flows. The mean annual precipitation and evapotranspiration are computed from ERA5 data (*79*) overlapping the study period. The environmental flow data are based on (*70*).

Supplementary Materials

This PDF file includes:
Figs. S1 to S8
Tables S1 and S2

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