Groundwater on the surface; up-to-date knowledge for the surface water hydrology and policy

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WaterAct
Joint actions for more efficient management of common groundwater resources

Keywords of presentation

1. **Some slides for introduction**
2. **Classification of the groundwater depending spring ecosystems**
3. **What is known about restoration of the spring ecosystems?**
4. **Is there any place of the spring ecosystems in the Water Framework Directive (WFD)?**

Hydrology *vs* Hydrogeology

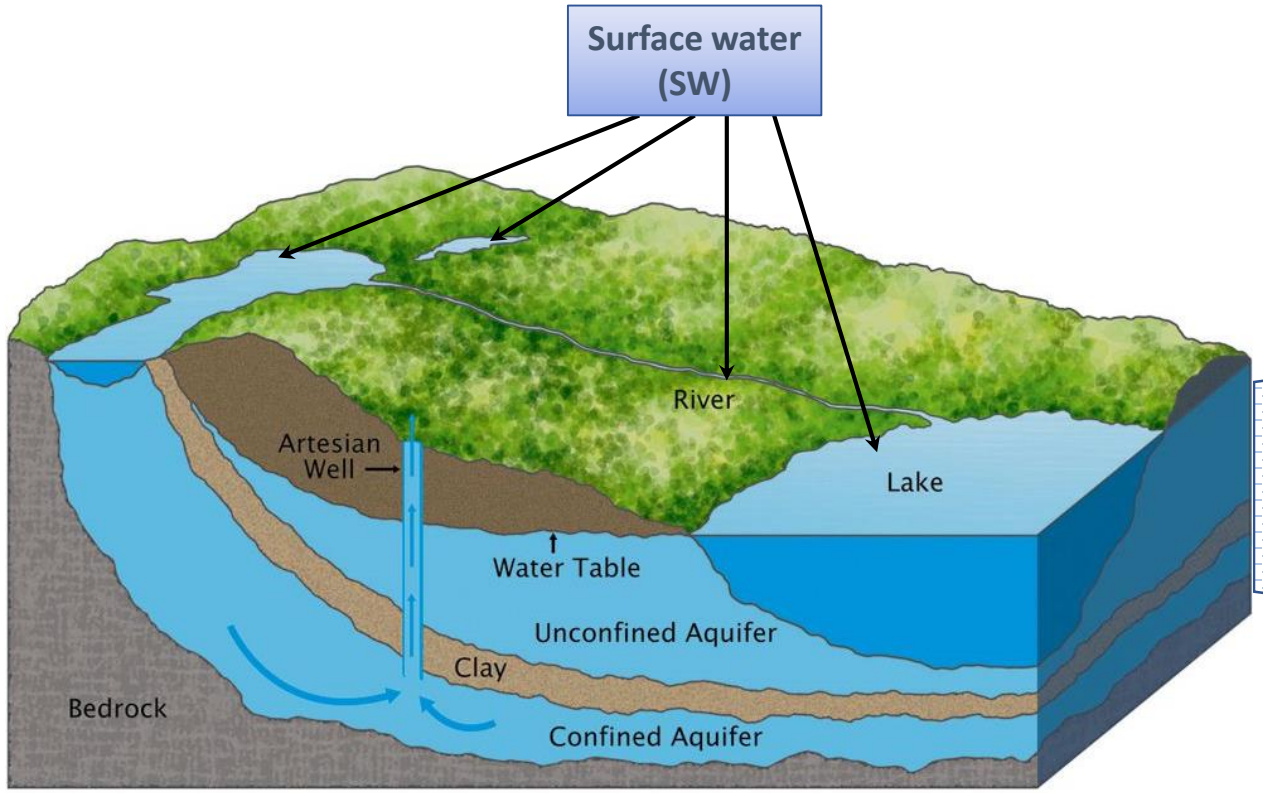
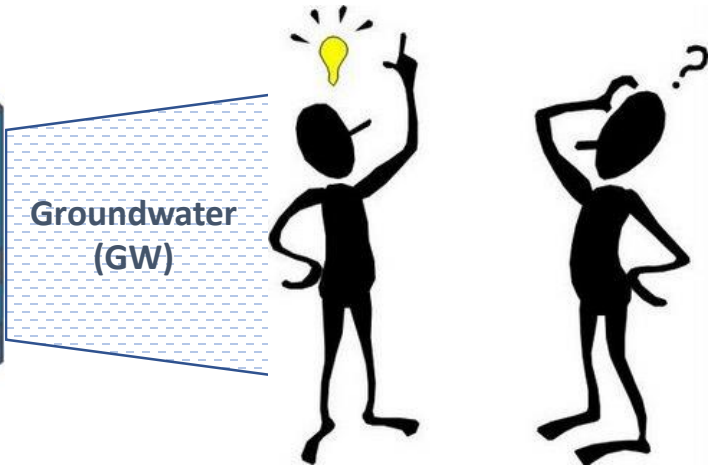


Image from: https://www.nationalgeographic.org/media/aquifer-illo/

In INTERREG *GroundEco* kick off meeting
5-6 July, 2018, Salacgriva, Latvia



HYDROGEOLOGIST

SURFACE WATER HYDROLOGIST

GDEs and GWDTEs

In INTERREG *GroundEco* kick off meeting
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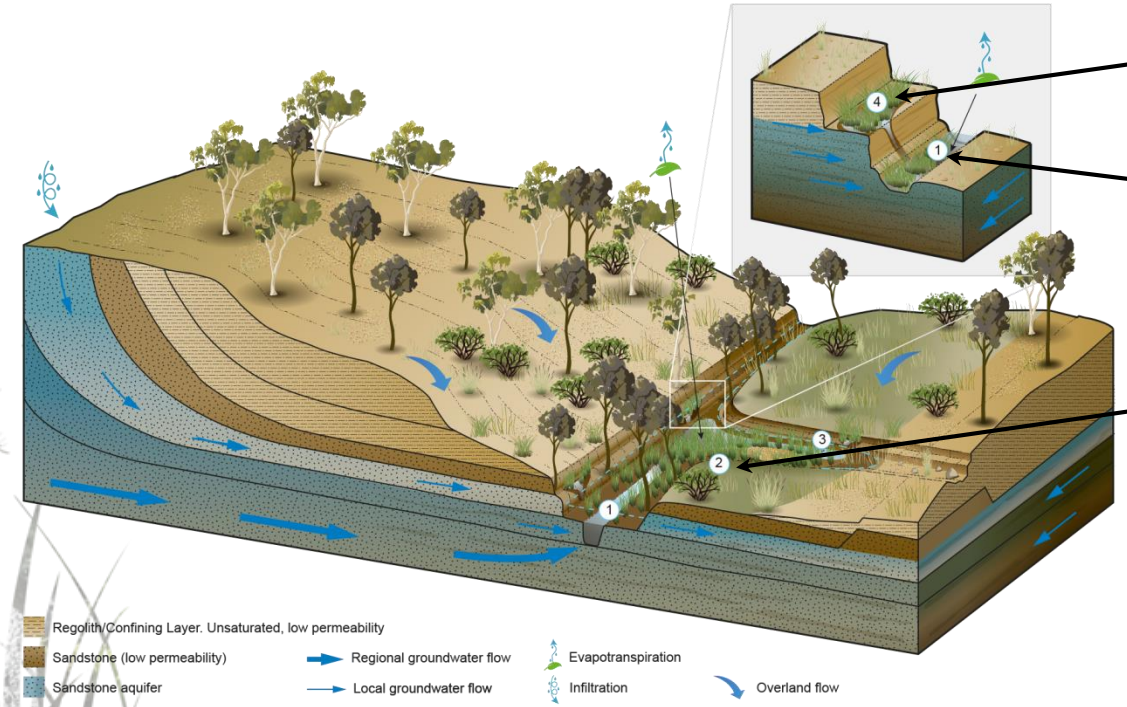
***What are the**

the *Groundwater-Dependent Ecosystems* (GDEs) and
the *Groundwater Dependent Terrestrial Ecosystems* (GWDTEs)?



Beside the
***Groundwater Dependent Terrestrial Ecosystems* (GWDTEs)**
there are:

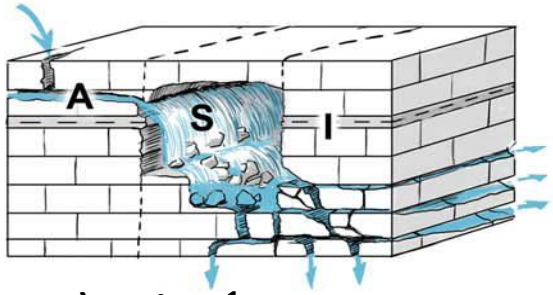
- Areas of ***seasonal*** **inundations with *local* groundwater (GW) discharge**, i.e. GW discharge could be both the permanent and seasonal
- Areas of ***permanent*** **GW discharge** which maintains ***saturation and pools of free water,*** with **aquatic species** within dominant; i.e. GW outlets could form the surface water bodies
- Areas with ***terrestrial wetlands*** adjacent to the creek line, i.e. what is the dynamic of GW discharges on the coasts of surface waterbodies

From: Queensland Government, Queensland (2017) Spring ecosystems of the Surat and southern Bowen Basins, Wetland*Info* website, accessed 6 October 2021. Available at: https://wetlandinfo.des.qld.gov.au/wetlands/ecology/aquatic-ecosystems-natural/groundwater-dependent/spring-ecosystems-of-the-surat-and-southern-bowen-basins/

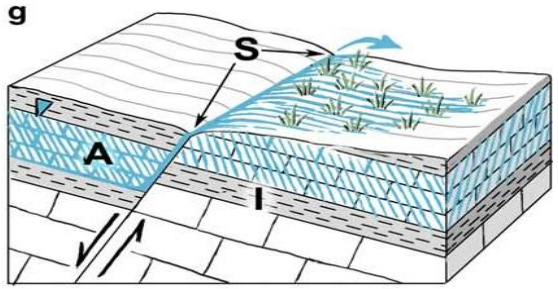
INTERREG *WaterAct* Handbook manuscript: *groundwater dependent ecosystems* (GDEs)

Based on publications:

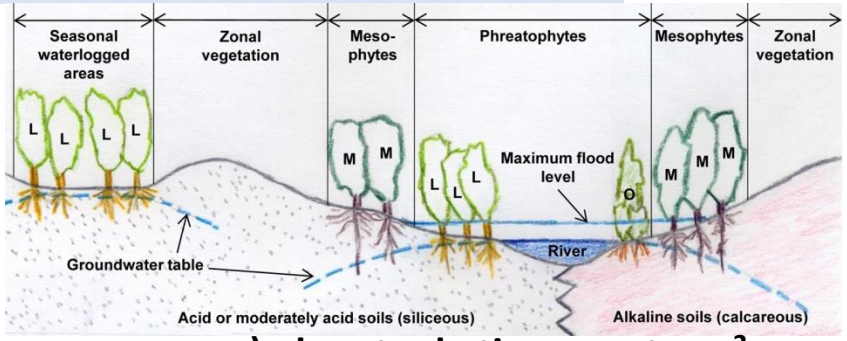
in worldwide there are **six types** of ***groundwater dependent ecosystems*** **(GDEs)** (Brown et al. 2010) :



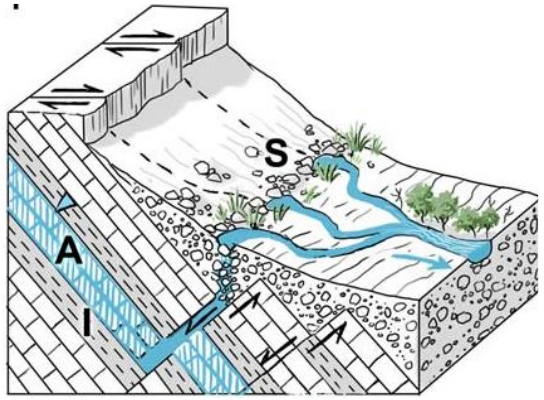
a) springs[1]



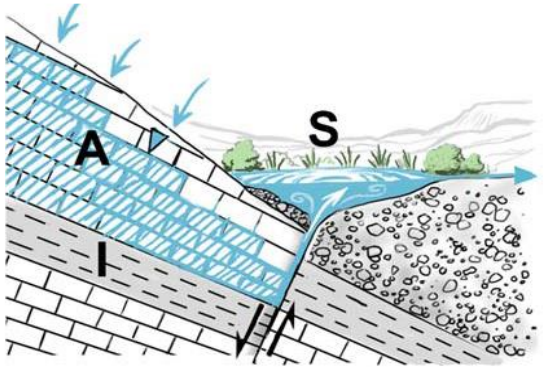
b) terrestrial wetlands[1]



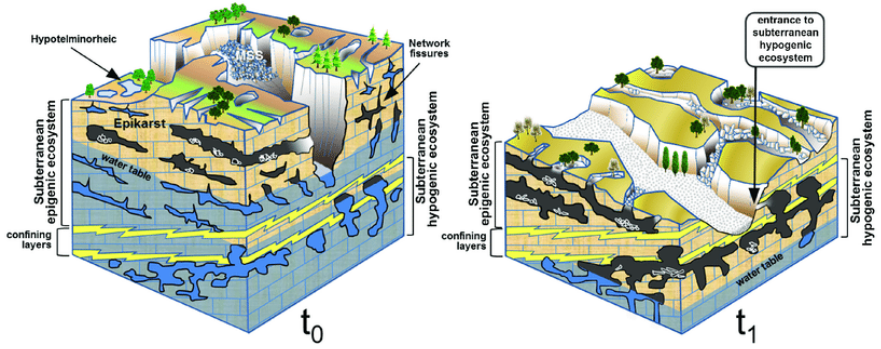
e) phreatophytic ecosystems[2]



c) rivers[1]



d) lakes[1]



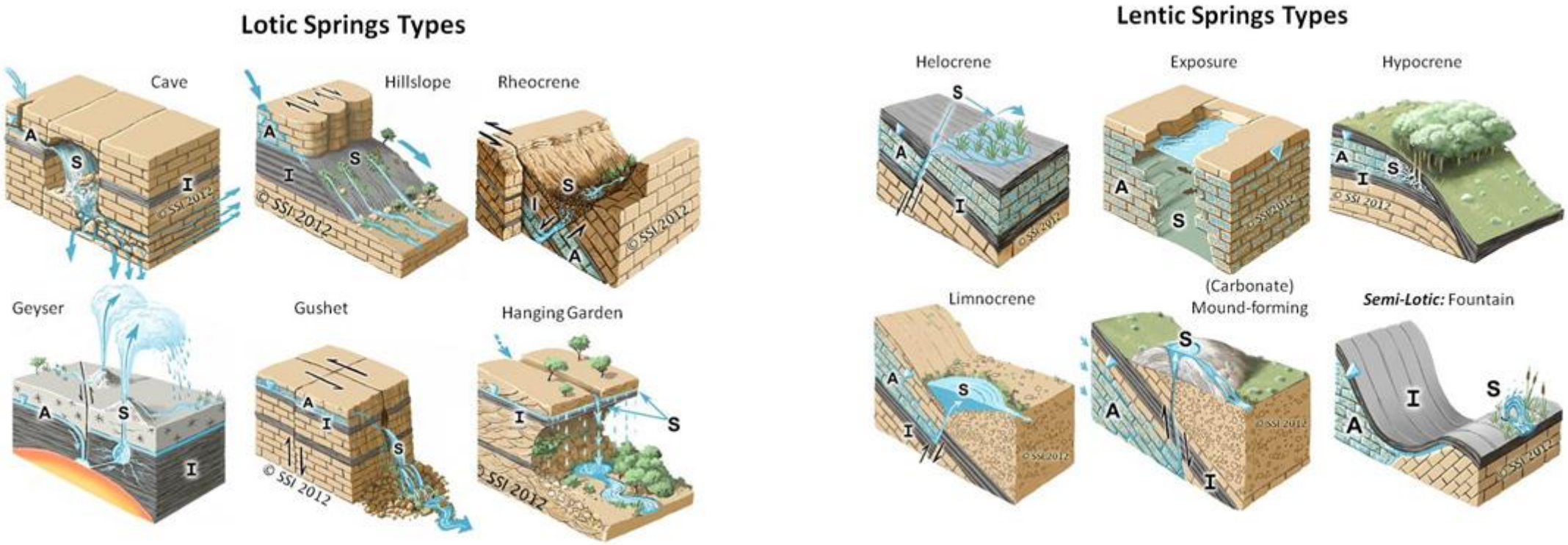
f) subterranean ecosystems[3]

The **springs** are the **only ecosystems** that are **fully associated with GW only.** The water supply of other GDEs partly may be ensured by the surface water (SW) and precipitation (P) (Brown et al. 2010).

Figures from: [1] Springer & Stevens, 2009, Stevens et al. 2016, SSI Webpage; 2 Venturas, M., Fuentes-Utrilla, P., López, R., et.al., 2015; [3]Sendra, A., Garay, P., Ortuño, et.al., 2014.

INTERREG *WaterAct* Handbook manuscript:
Lotic and *Lentic* ecosystems *of springs*

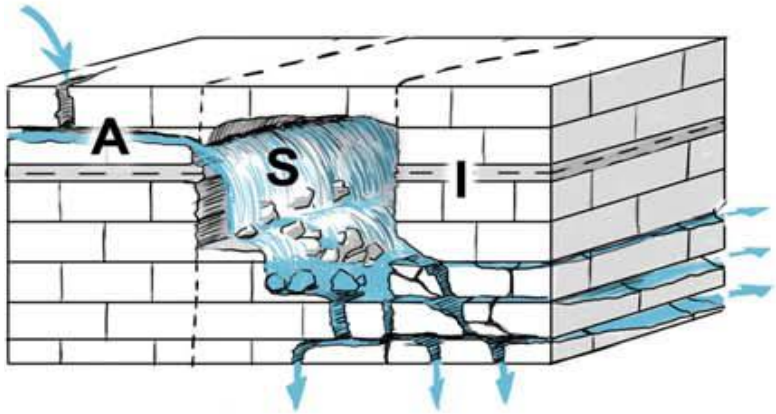
The ***springs as an ecosystems*** on the surface could be divided into **the *lotic* i.e. flowing water** and ***lentic*** **i.e. standing water ecosystems** (Stevens et al. 2016).

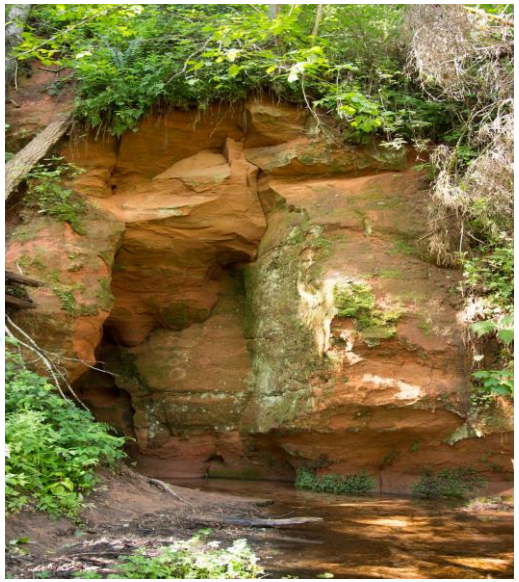


From: Stevens, L.E., Ledbetter, J.D., Springer, A.E., Campbell, C., Misztal, L., Joyce, M., Hardwick, G. **2016**. **Arizona Springs Restoration Handbook.** Spring Stewardship Institute, Museum of Northern Arizona, Flagstaff, Arizona and Sky Island Alliance, Tucson, Arizona: 126 pp. http://docs.springstewardship.org/PDF/SIA-Handbook_010916.pdf

INTERREG *WaterAct* Handbook manuscript:
Do we have the *Lotic* ecosystems of the *springs?*

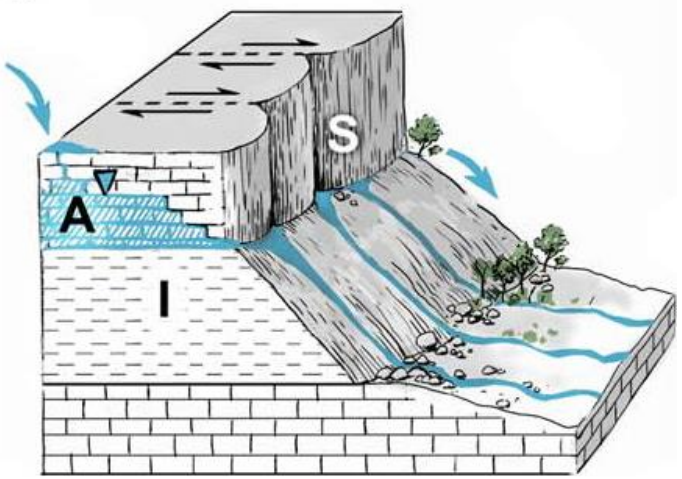
Cave spring
of the karst terrain *





Estonian **Merioone cave spring** in nature[1]

Hillslope spring
of sloping land *



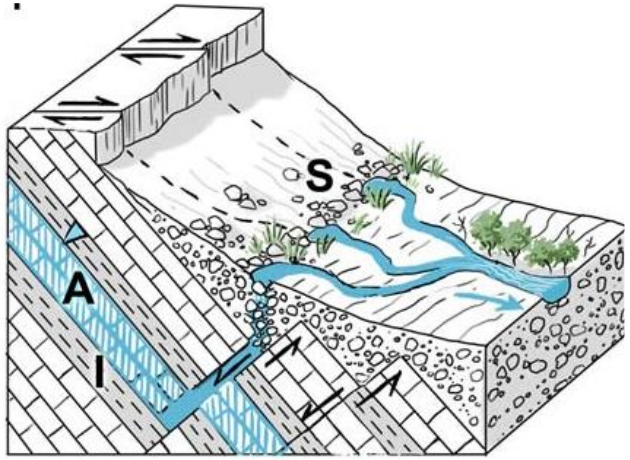
A - groundwater aquifer,
I - impermeable stratum,
S - spring.

Estonian **Viidumäe hillslope springs** in nature (photo: M. Vainu).

*Generalised diagrams of Springer & Stevens, 2009, Stevens et al. 2016, SSI Webpage; [1]Photo is downloaded from: https://www.facebook.com/eestigeoloog/posts/386468704810450/).

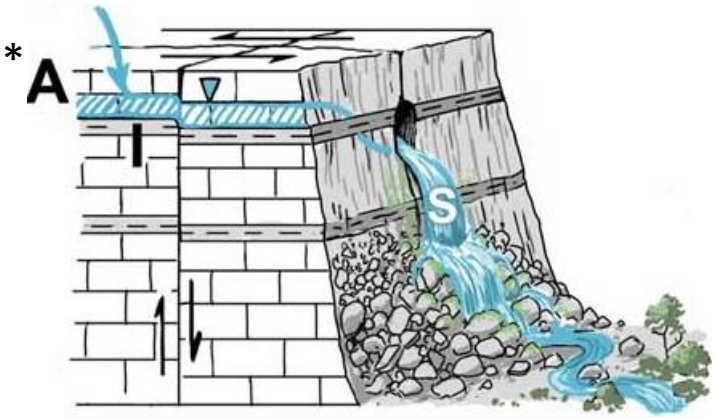
INTERREG *WaterAct* Handbook manuscript:
Do we have the *Lotic* ecosystems of the *springs?*

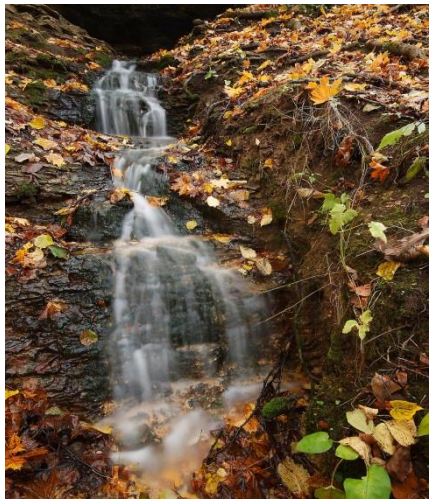
Rheocrene springs
or flowing springs *



Estonian **Lavi rheocrene spring** in nature (photo: M. Vainu).

Gushet springs
of nearly vertical cliffs *





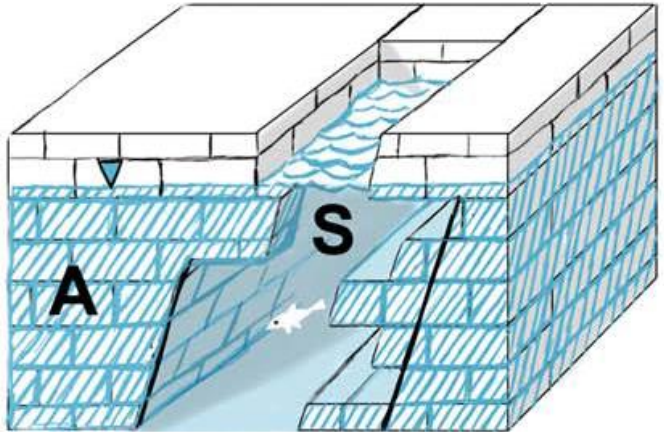
Estonian **gushet spring** of **Salumäe Silmaallikas** in nature[2]

A - groundwater aquifer,
I - impermeable stratum,
S - spring.

*Generalised diagrams of Springer & Stevens, 2009, Stevens et al. 2016, SSI Webpage; [2]Photo is downloaded from: https://www.maavald.ee/en/image-contests/2009/arthurarnwald-salumaesilmaallikas-jpg-260

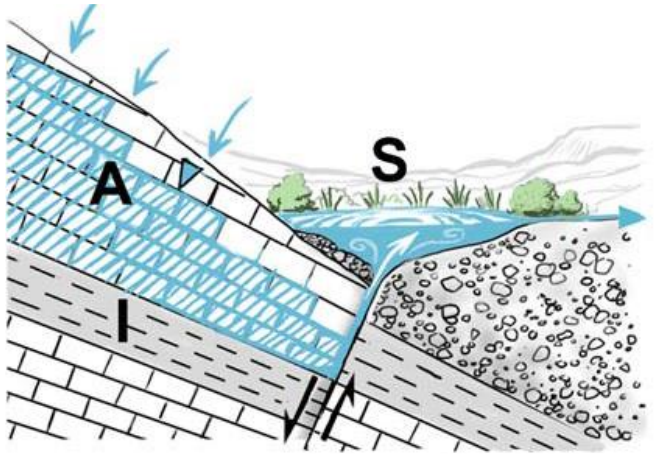
INTERREG *WaterAct* Handbook manuscript:
Do we have the *Lentic* ecosystems of the *springs?*

Exposure spring, where a water table is exposed without flowing at the Earth's surface.*

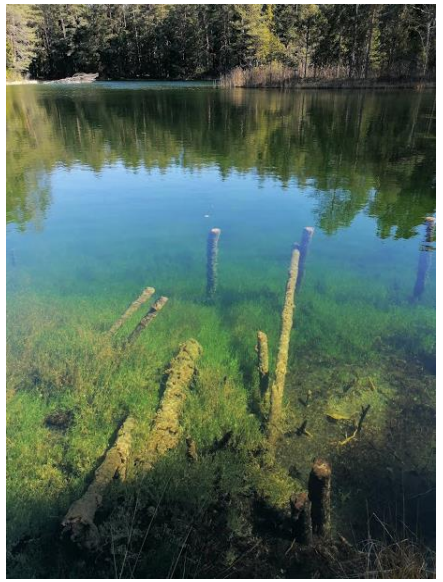


Estonian Sopa **exposed spring**[5]

Limnocrene spring, they emerge into an open pool of water as confined or unconfined GW aquifers.*



A - groundwater aquifer,
I - impermeable stratum,
S - spring.

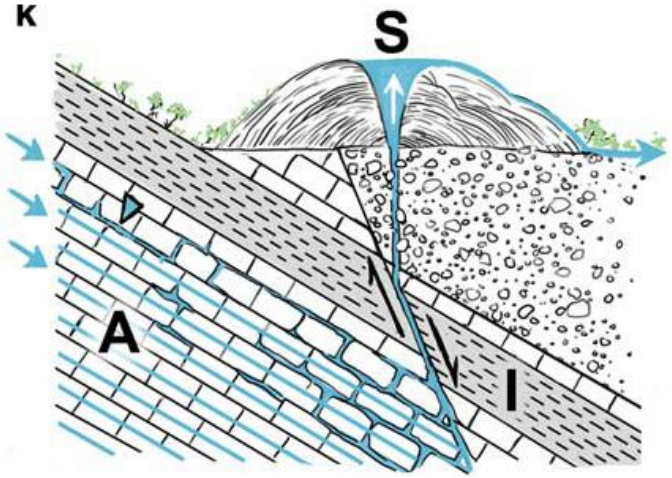


Estonian **limnocrene Äntu Sinijärv Lake**[5]

*Generalised diagrams of Springer & Stevens, 2009, Stevens et al. 2016, SSI Webpage; [5]Photo downloaded from: http://ritassilla.blogspot.com/2020/04/antu-sinijarved.html

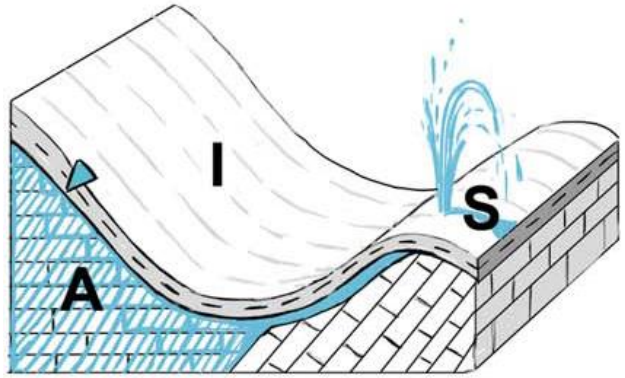
INTERREG *WaterAct* Handbook manuscript:
Do we have the *Lentic* ecosystems of the *springs?*

(Carbonate) mound-forming springs, they form elevated calcium carbonate or organic peat mounds, from which GW emerges and usually flows.*



Estonian **Varimõisa carbonate mound spring** in nature (photo: M. Vainu).

Semi-Lotic Fountain springs, can be also an anthropogenic, formed by drilling into an artesian aquifer



A - groundwater aquifer,
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S - spring.

Estonian man induced **Purskav fountain spring** in nature[3]

It was formed accidentally in 1980 by the drilling. At the beginning the height of the fountain were almost a meter. Nowadays the water pressure has dropped, but during high water seasons it has the height of 0.7 m.[4]

*Generalised diagrams of Springer & Stevens, 2009, Stevens et al. 2016, SSI Webpage; ; [3]Photo is downloaded from: https://visitjarva.ee/matkarajad-norra-allikate-alal/; [4]In: Vilbaste, K., 2013. Eesti allikad. Tallinn: Varrak.

INTERREG *WaterAct* Handbook manuscript:

What are the *seeps?*

The **Seep Research** explains: "A ***seep*** or ***flush*** is **a moist** or **wet place where water, usually groundwater**, reaches the earth's surface from an underground aquifer."

Spring *vs* Seep

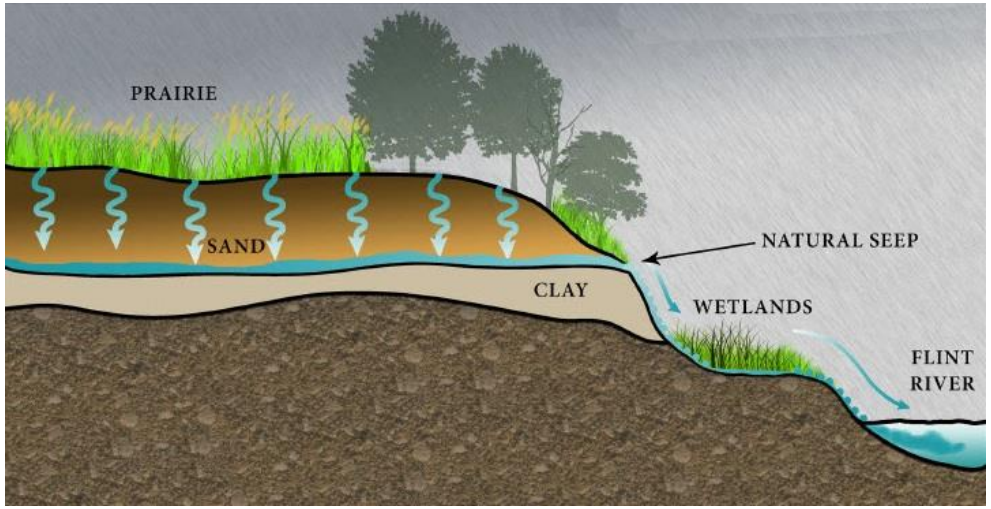
*In ***springs*** the GW discharging out from a **single point**

⇒ In ***seeps*** the GW discharging **diffusely over a larger area**, having no well-defined origin.

***Seeps** generally have a **lower flow rate** than **springs;**

i.e. low flow: **<0.01 m3/s;** medium flow**: 0.01-0.5 m3/s;** and high flow**: >0.5 m3/s** (Williams , 2016);

***Seeps** seldom have a **volume large enough to form a stream or even measure**.



From: Seep or Spring at Richfield Park;
https://www.geocaching.com/geocache/GC75N2R_seep-or-spring-at-richfield-park?guid=7af98a18-8840-45c3-a8e6-ba96369f75ba

A seep puddle in a forest clearing
From:
https://en.wikipedia.org/wiki/Seep_(hydrology)#/media/File:Pond_in_a_forest_clearing_bgiu.jpg

INTERREG *WaterAct* Handbook manuscript:

What are the *seeps?*

Seeps mostly occur in **lower elevation** areas because water runs downhill, but can happen **higher up** if the GW present is abundant enough.

(A) **GW seeps** at the contact between Tuha **Sandstone** and underlying **siltstone** of the Tikapu Formation, Rangitikei Group, exposed in cliffs in the Rangitikei River valley.

(C) **GW seeps** within Mangaonoho Formation, Rangitikei Group at contact with **laminated sandstone** over **massive siltstone**

From: Rees, C., Palmer, J., Palmer, A., Singh, R., 2018. Landscape evolution and hydrogeochemical characteristics of the Pourewa Stream catchment, lower North Island, New Zealand; DO - 10.1080/00288306.2018.1541812

INTERREG *WaterAct* Handbook manuscript:
The common stressors of GW feeding springs

Lotic springs	The common stressors	Lentic springs	The common stressors
Cave	**GW extraction**, pollution, **recreation**	Helocrene	GW extraction, livestock water supplies (creation of open water), agricultural hay-mowing, urbanization, road construction (may dewater the downslope portion), **peat mining**, recreation, non-native species introduction, climate change.
Hillslope	GW extraction, recreation, non-native species introduction, **climate change**	Exposure	GW extraction, pollution, recreation, filling/dredging, non-native species introduction, climate change.
Rheocrene	GW extraction, livestock water supplies, agricultural hay-mowing, urbanization, road construction, recreation, **non-native species introduction**, climate change.	Hypocrene	GW depletion, urbanization, livestock grazing, non-native species introduction, climate change
Gushet	GW and surface water extraction, livestock water supplies, recreation, non-native species introduction, climate change	Limnocrene	GW depletion, agricultural and mining pollution, **urbanization,** pond margin habitat alteration, livestock grazing, recreation, non-native species introduction, climate change.
Hanging Garden	GW and surface water extraction, livestock water supplies, recreation, non-native species introduction, climate change	(Carbonate) mound forming	GW depletion; agricultural and mining pollution; urbanization, pond margin habitat alteration, livestock grazing/soil compaction, recreation, non-native species introduction, climate change.
		Semi-Lotic Fountain spring	GW extraction, pollution, livestock water supplies, recreation, non-native species introduction, climate change.

INTERREG *WaterAct* Handbook manuscript:
Restoration

*The term ***restoration*** **means the reestablishment of pre-disturbance ecosystem functions** and related physical, chemical, and biological characteristics (e.g., National Research Council 1992).

***Restoration** requires one or more of **the following processes**:

a) reconstruction of previous physical conditions;

b) chemical adjustment of the soil and water; and

c) biological manipulation, including the reintroduction of absent native flora and fauna

***Restoration** aims to return an ecosystem to a former natural condition,

the terms ***creation*, *reclamation***, and ***rehabilitation*** - putting a landscape to a new or altered use to serve a particular human purpose (creation or reclamation)

***Restoration** of GW dependent ecosystems, incl. Groundwater Dependent Terrestrial Ecosystems very complicated and complex activity, therefore any kind of project activity should start from compilation of relevant **Questionnaire**

(**in Stevens et al. 2016 suggested 18 questions**)

INTERREG *WaterAct* Handbook manuscript:
Restoration

Example list of **stewardship prioritise criteria** (copy of Stevens et al. 2016) for **restoration planning of GDEs**

Stewardship Criteria	Weighted Importance Value
1) Ease of restoration	1
2) Water rights ownership	0.9
3) Presence of federally listed species	0.8
4) Ease of return to natural sphere of discharge	0.7
5) Absence or ease of eradication of exotic species	0.6
6) Occurrence of springs in priority watershed	0.5
7) Presence of culturally or historically sensitive springs	0.4
8) Ease of exclusion of ungulates from source	0.3
9) Ease of improving access by native animals	0.2
10) Proximity to municipalities	0.1

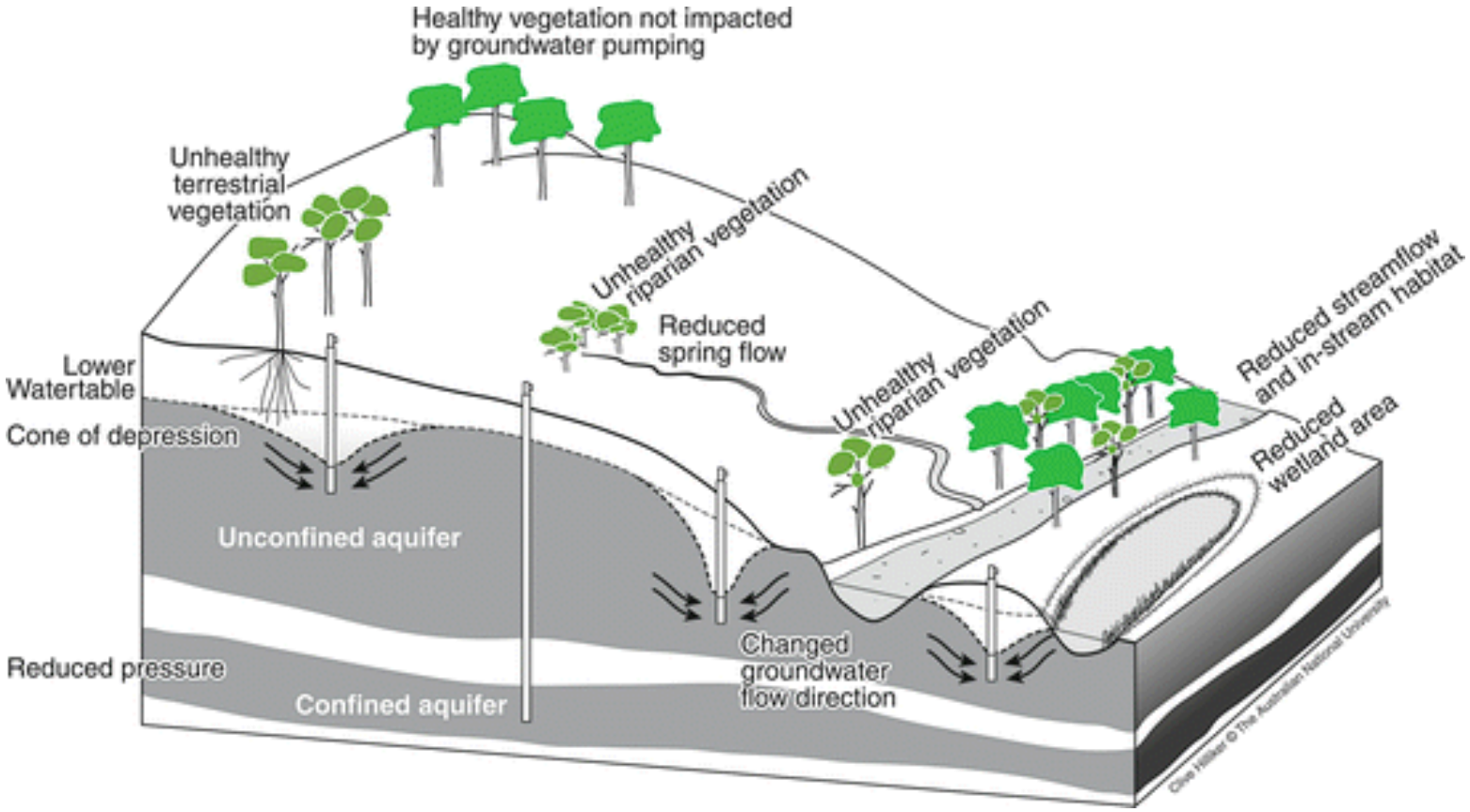
INTERREG *WaterAct* Handbook manuscript:
Restoration

In short:
*the type of restorative action is strongly dependant on the particular interests of the restoration management,
*restoration projects may be focused on one particular aspect of the springs ecosystem (partial restoration), or are interested in restoring the full ecosystem (full restoration). (Stacy et al. 2011)

Strategical start for planning of restoration activity of any GDEs: i.e.,
(1) definition of the response function of ecosystems to changes in GW availability or GW quality;
(2) determination of the threshold for GDEs beyond which unacceptable changes in GDE structure and function occur; and
(3) a mechanistic understanding (and hence predictive capacity) of the interaction of future climate variability on GDEs.

INTERREG *WaterAct* Handbook manuscript:
Restoration

Example diagram showing the potential impacts of groundwater pumping on GDEs

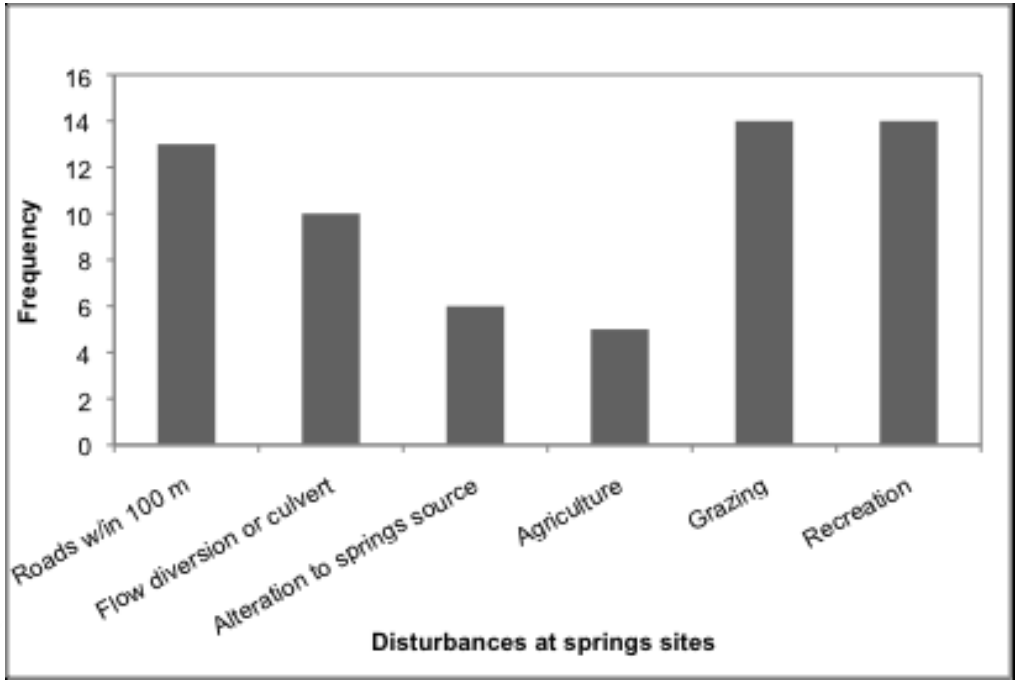


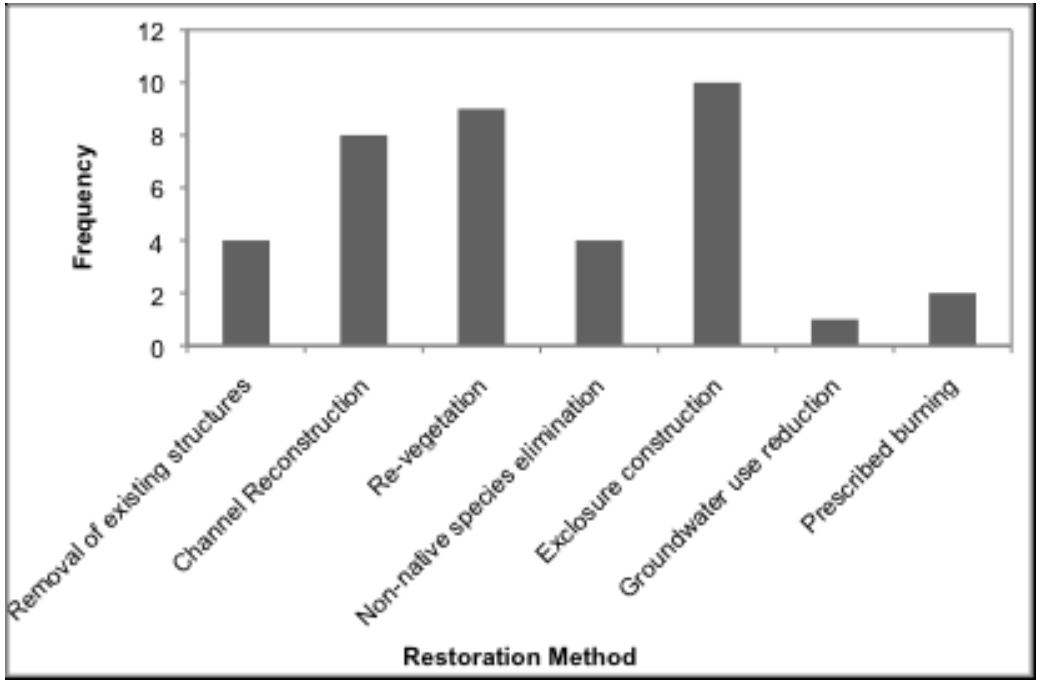
(In: Eamus D., Fu B., Springer A.E., Stevens L.E. (2016) Groundwater Dependent Ecosystems: Classification, Identification Techniques and Threats. In: Jakeman A.J., Barreteau O., Hunt R.J., Rinaudo JD., Ross A. (eds) Integrated Groundwater Management. Springer, Cham. https://doi.org/10.1007/978-3-319-23576-9_13)

INTERREG *WaterAct* Handbook manuscript:
Restoration

HAVE ARID LAND SPRINGS RESTORATION PROJECTS BEEN EFFECTIVE IN RESTORING HYDROLOGY, GEOMORPHOLOGY, AND INVERTEBRATE AND PLANT SPECIES COMPOSITION COMPARABLE TO NATURAL SPRINGS WITH MINIMAL ANTHROPOGENIC DISTURBANCE?

(compiled by: STACEY, C.J. (NÉE DAVIS), SPRINGER, A. E.1 & STEVENS, L.E.)





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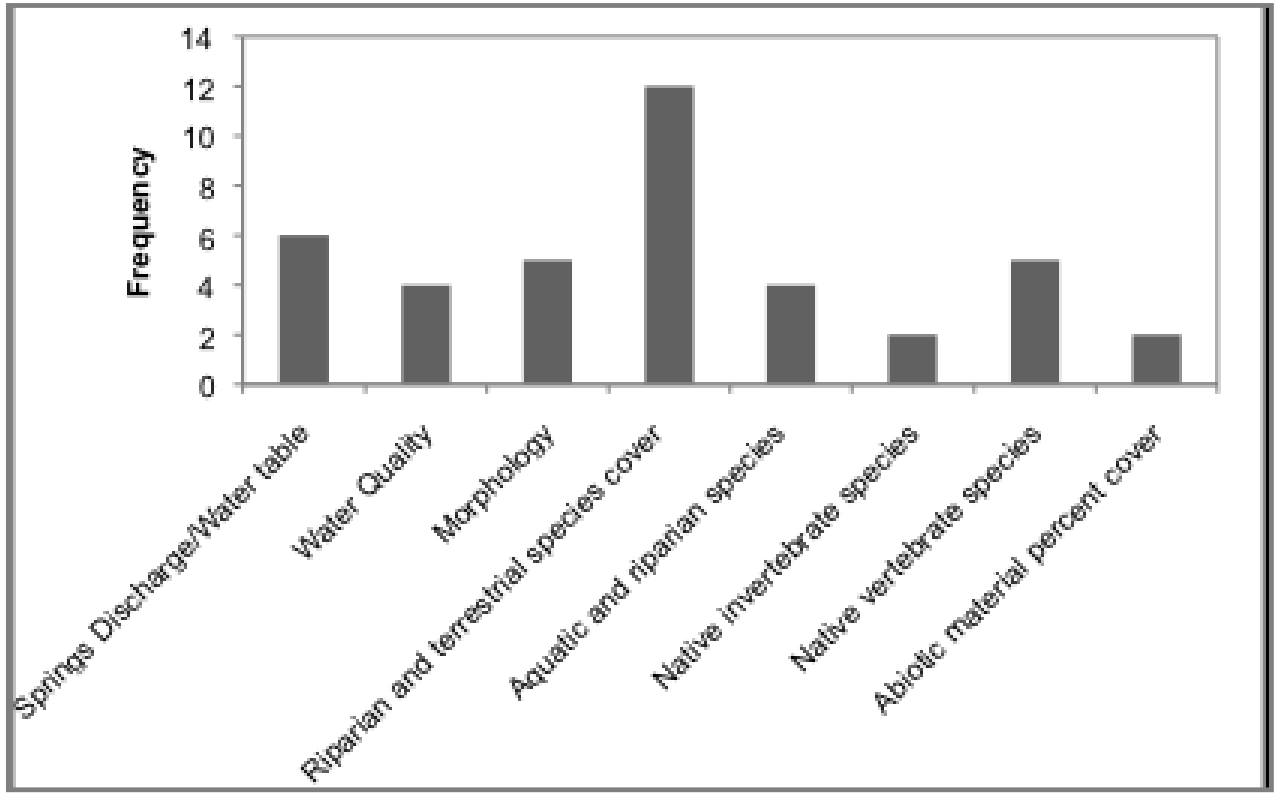
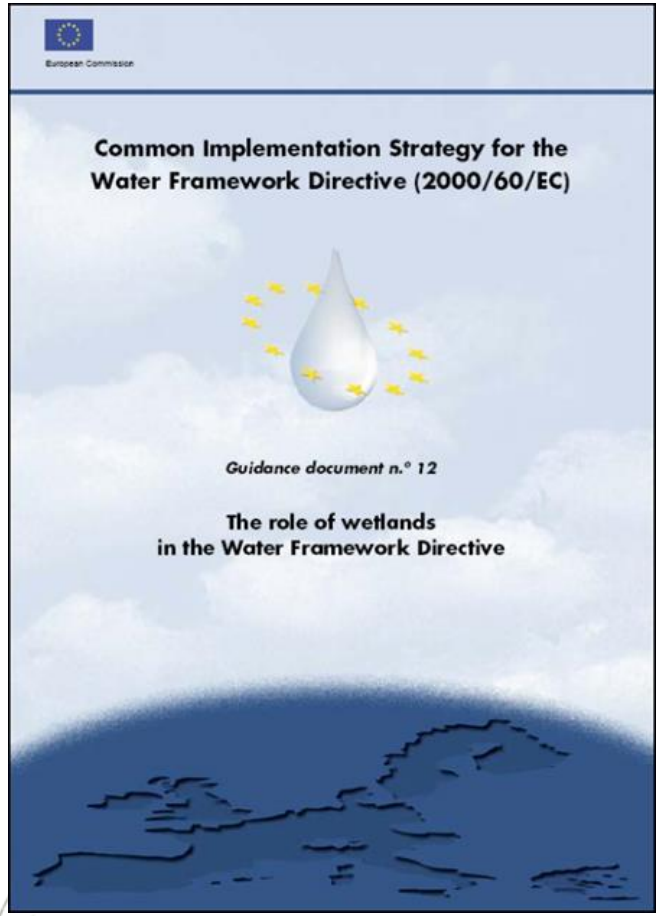


Criteria measured after restoration

INTERREG *WaterAct* Handbook manuscript:
The Role of Wetlands in the Water Framework Directive (WFD)



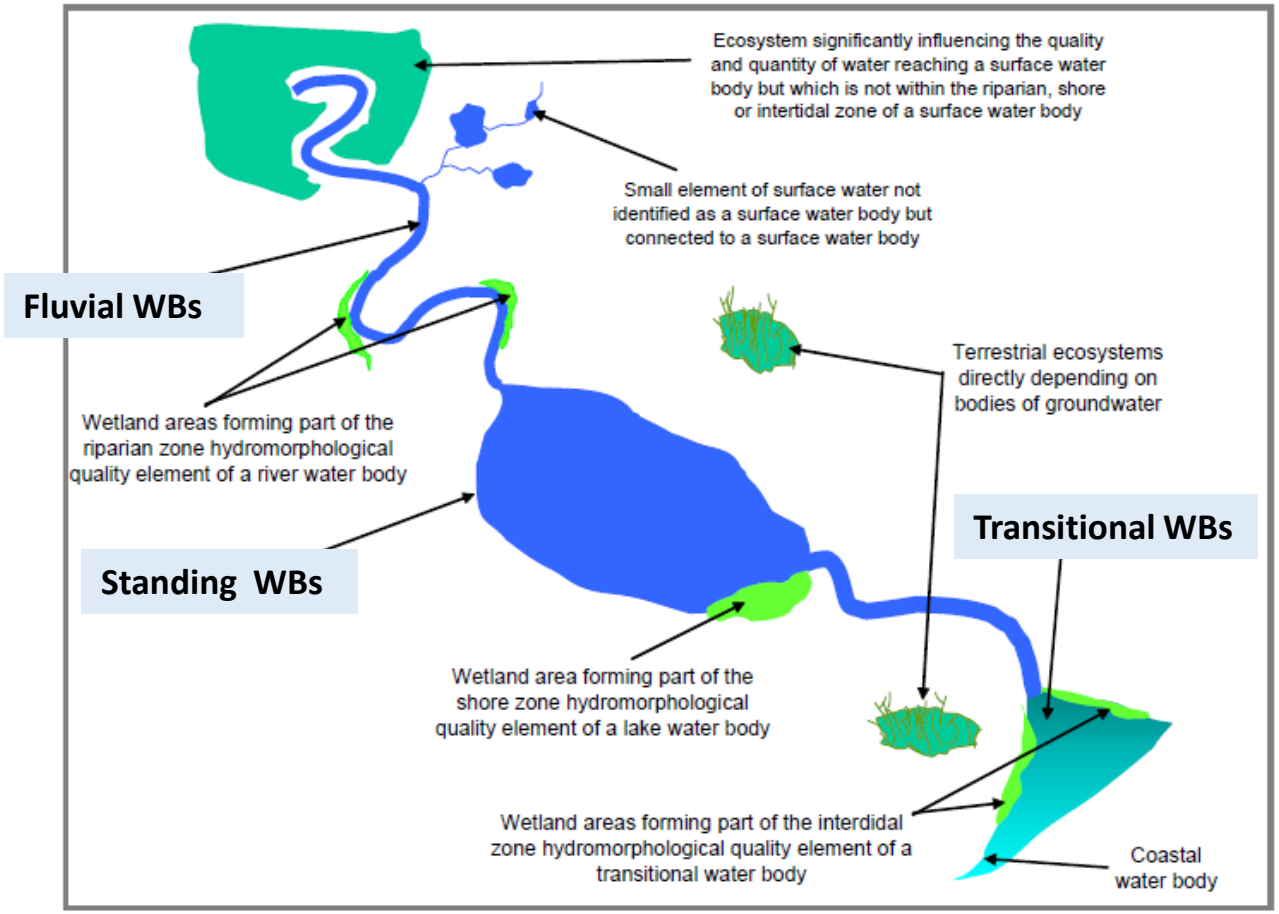
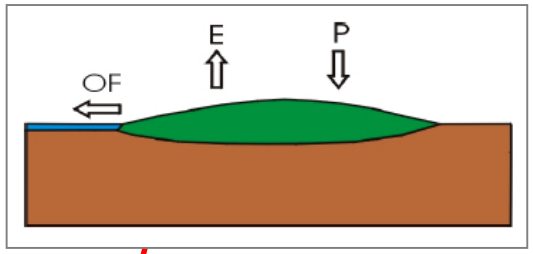
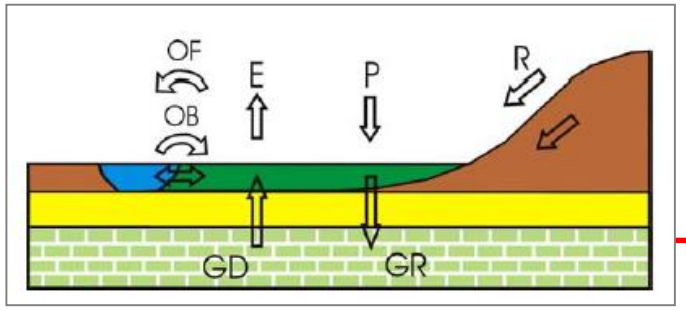


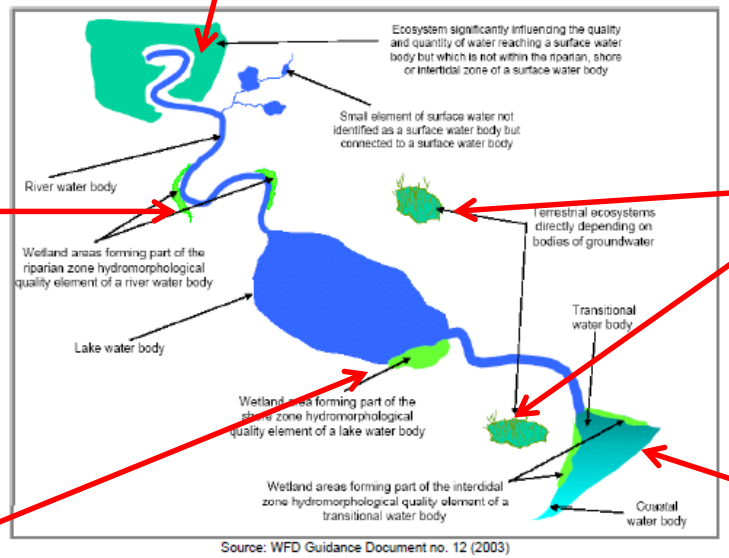
Figure 2: Ecosystems within a river basin that may be relevant to the achievement of the Directive's objectives (map chart)

INTERREG *WaterAct* Handbook manuscript:
The Role of Wetlands in the Water Framework Directive (WFD)

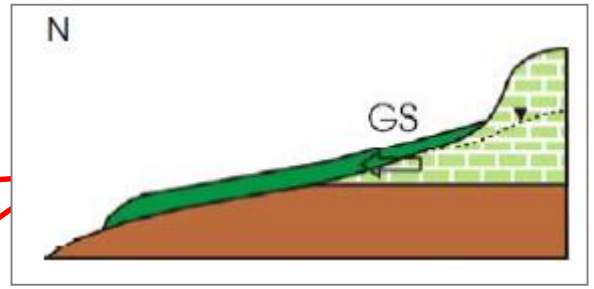




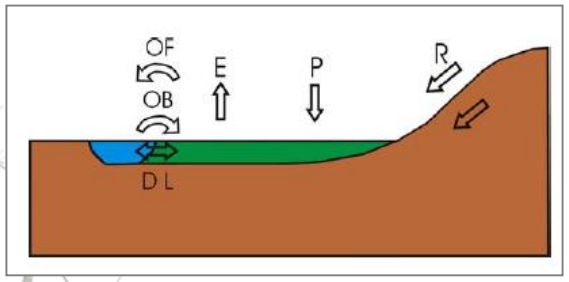
Riparian wetland



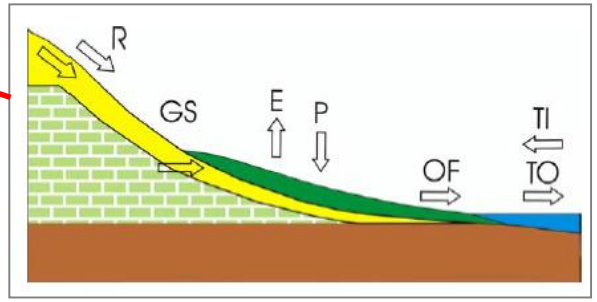
Source: WFD Guidance Document no. 12 (2003)



GWD terrestrial ecosystems



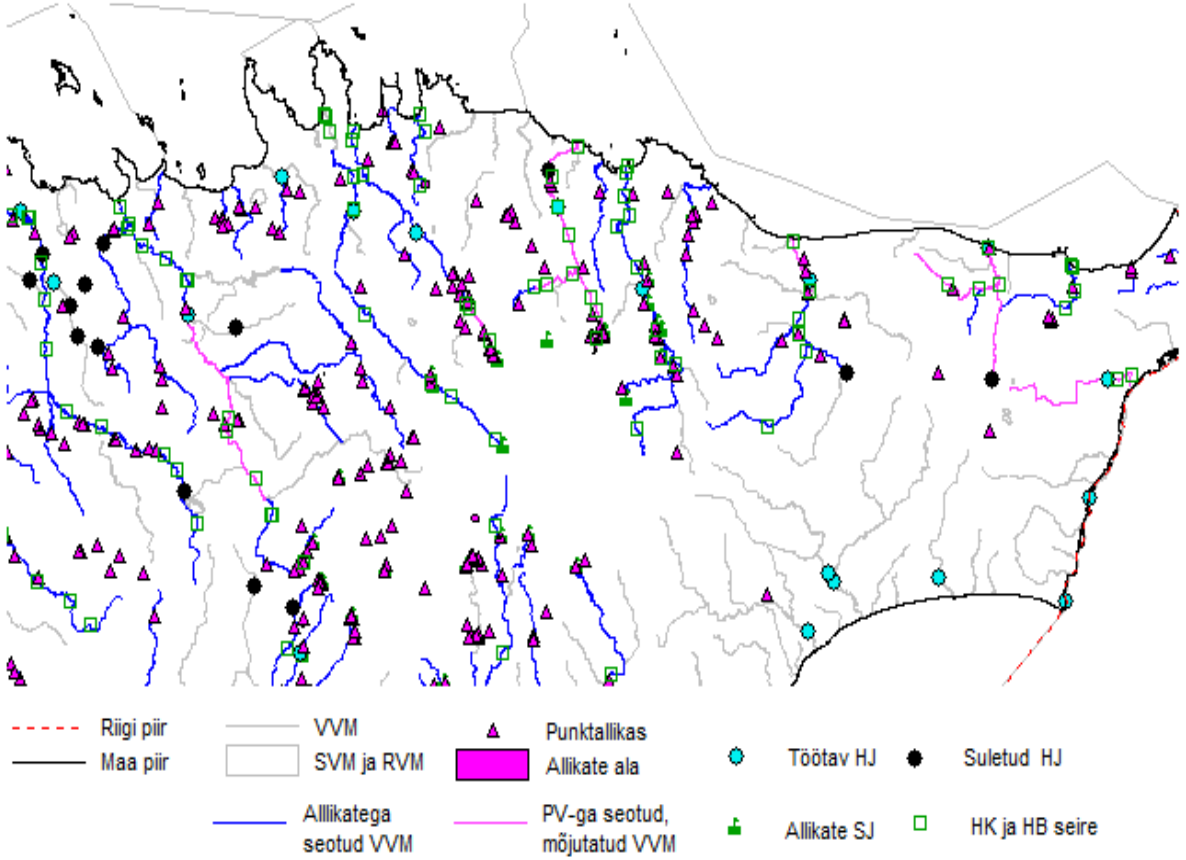
Costal wetland



Transitional water body

Conceptual schemes from: Maltby, et al., 2003. Integration of European Wetland Research in Sustainable Management of the Water Cycle, EUROWET

Is there any place for the spring ecosystems in the Water Framework Directive (WFD)?



From: Terasmaa, J., et al., 2014. Põhjaveekogumi veest sõltuvad ökosüsteemid, nende seisundi hindamise kriteeriumid ja seirevõrk

Fluvial water body (WBs) in WFD

* The “water body” should be a coherent sub-unit in the **river basin (district)** to which the environmental objectives of the directive must apply.
Hence, the main purpose of identifying “water bodies” is to enable the status to be accurately described and compared to environmental objectives .

* The Directive only requires sub-divisions of surface water and groundwater **that are necessary for the clear, consistent and effective application of its objectives**. Sub-divisions of surface water and groundwater into smaller and smaller water bodies that do not support this purpose should be avoided.

From: https://circabc.europa.eu/sd/a/655e3e31-3b5d-4053-be19-15bd22b15ba9/Guidance%20No%202%20-%20Identification%20of%20water%20bodies.pdf

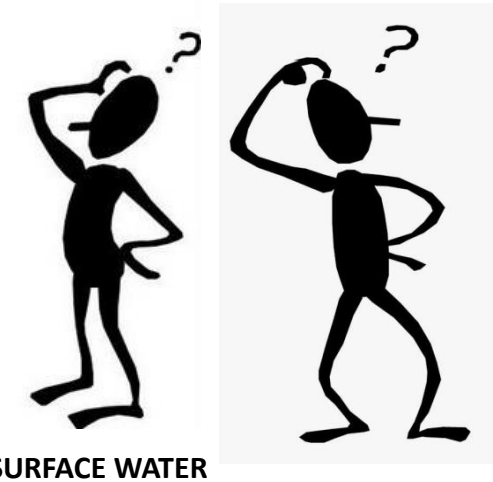
Is there any place for the spring ecosystems in the Water Framework Directive (WFD)?

In WFD,
2. GROUNDWATERS

2.1. Via characterisation of groundwater bodies should be identified :
"…- those groundwater bodies for which there are directly dependent surface water ecosystems or terrestrial ecosystems."

From:
https://eur-lex.europa.eu/resource.html?uri=cellar:5c835afb-2ec6-4577-bdf8-756d3d694eeb.0004.02/DOC_1&format=PDF

Fluvial water body (WBs)
***vs* GDEs**



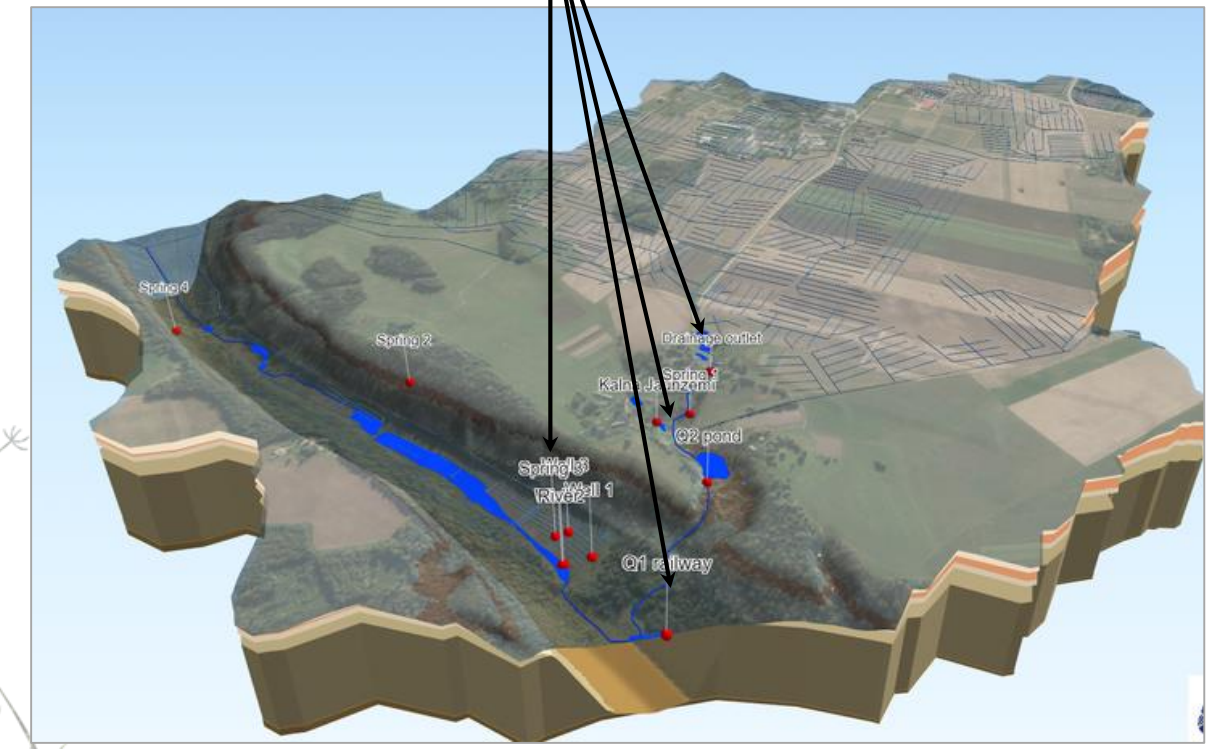
SURFACE WATER HYDROLOGIST

HYDROGEOLOGIST

Is there any place for the spring ecosystems in the Water Framework Directive (WFD)?

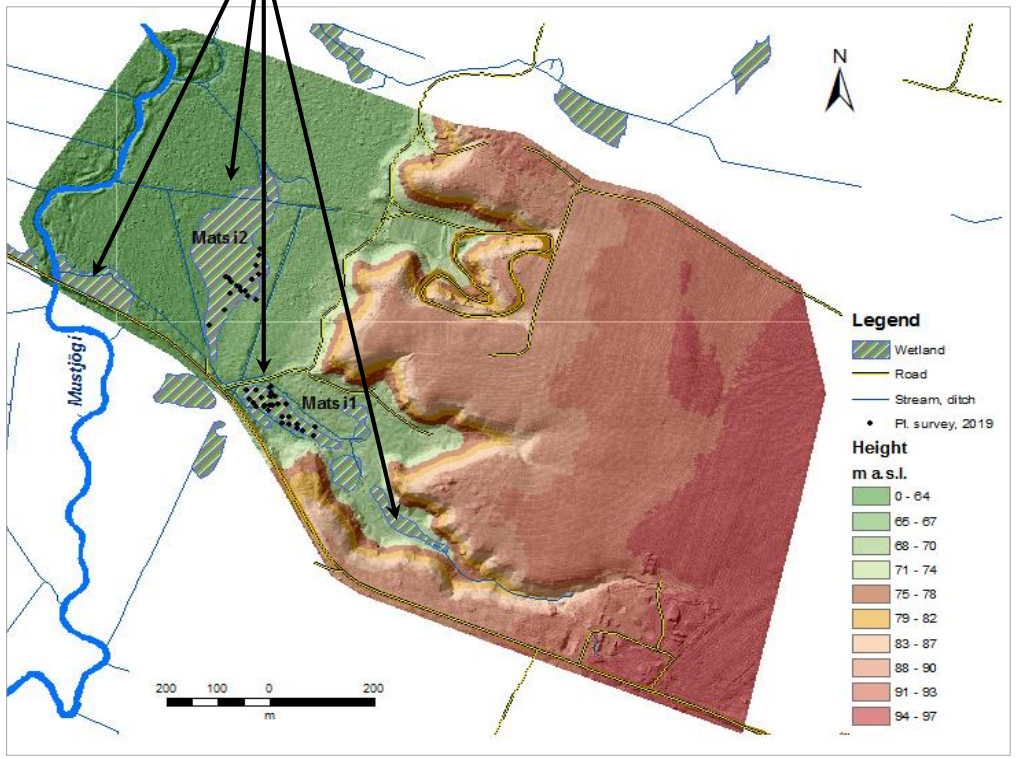
GDEs - are all a function of their hydrological, geological, and climatic setting

Springs in Latvia



From: INTERREG GroundEco, Retike, I., Kalvāns, A., Priede, A., et.al., 2020

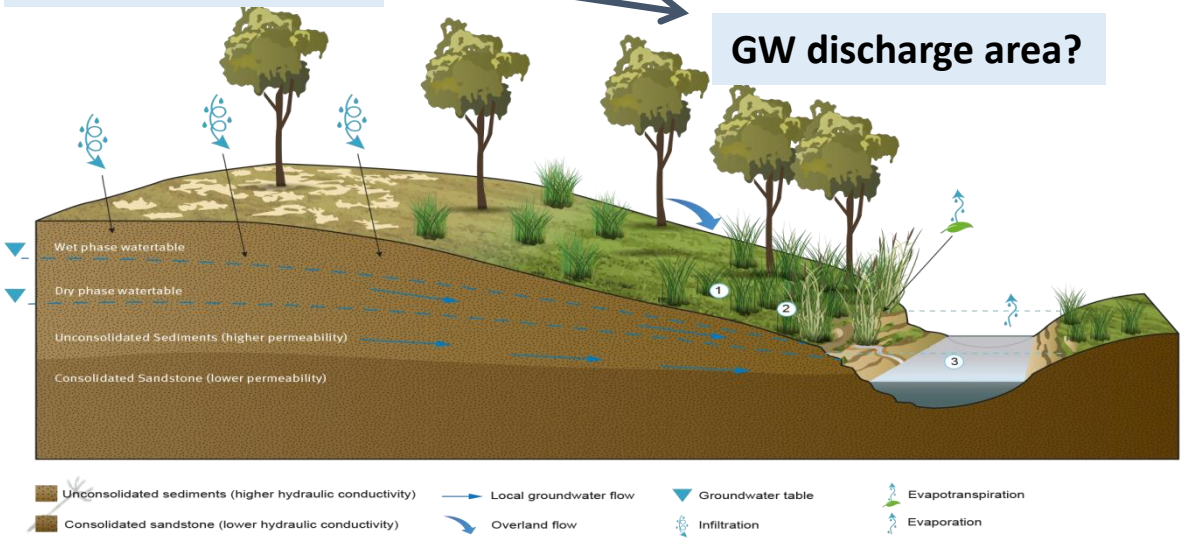
Terrestrial Wetlands in Estonia

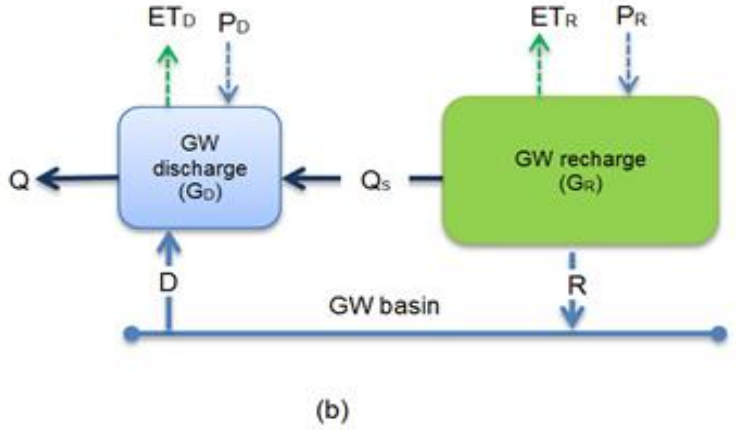


Is there any place for the spring ecosystems in the Water Framework Directive (WFD)?

GDEs - are all a function of their recharge and discharge settings

GW recharge area? ⟷ **GW discharge area?**





$$Q = P + ET + \Delta S_s + \Delta S_G$$

Where:
P - the precipitated amount of water on the SW basin,
Q - the SW discharge out from the SW basin,
ET - the evapotranspiration from the SW basin,
ΔS_s - the change in water storage of the SW reservoir, and
ΔS_G - the change in water storage of the GW reservoir (both saturated and unsaturated conditions) during for instance *annual* recording *period* (In: Freeze & Cherry 1979).

NB! The GW **recharge and discharge areas** in the landscape can be described as
recharge areas at local heights and **discharge areas at local depressions**.
The area in between can be a ***discharge area during wet periods*** and ***recharge area during dry periods.***

The left scheme from: Queensland Government, Queensland (2017) Spring ecosystems of the Surat and southern Bowen Basins, Wetland*Info* website, accessed 6 October 2021. Available at: https://wetlandinfo.des.qld.gov.au/wetlands/ecology/aquatic-ecosystems-natural/groundwater-dependent/spring-ecosystems-of-the-surat-and-southern-bowen-basins/; The right scheme from: **INTERREG *WaterAct* Handbook manuscript**

The Role of Wetlands in the Water Framework Directive (WFD)

Is there any place for the spring ecosystems in the Water Framework Directive (WFD)?

GDEs recharge and discharge settings are parameters that change over time and space

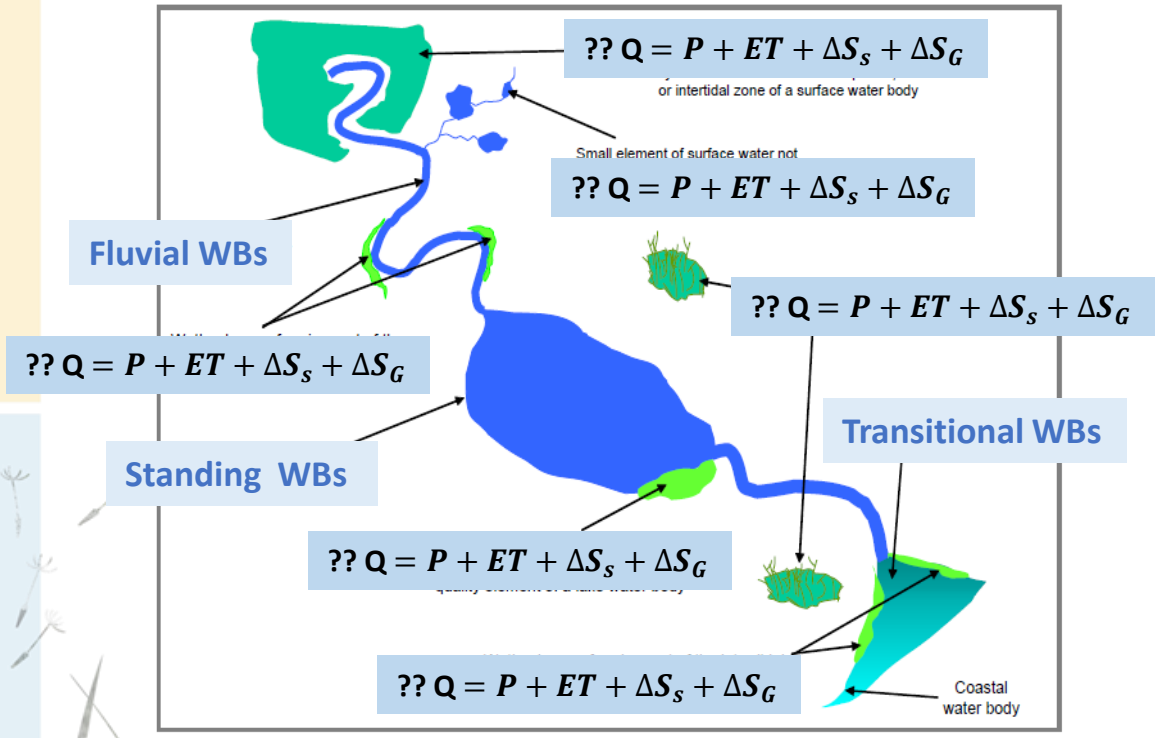
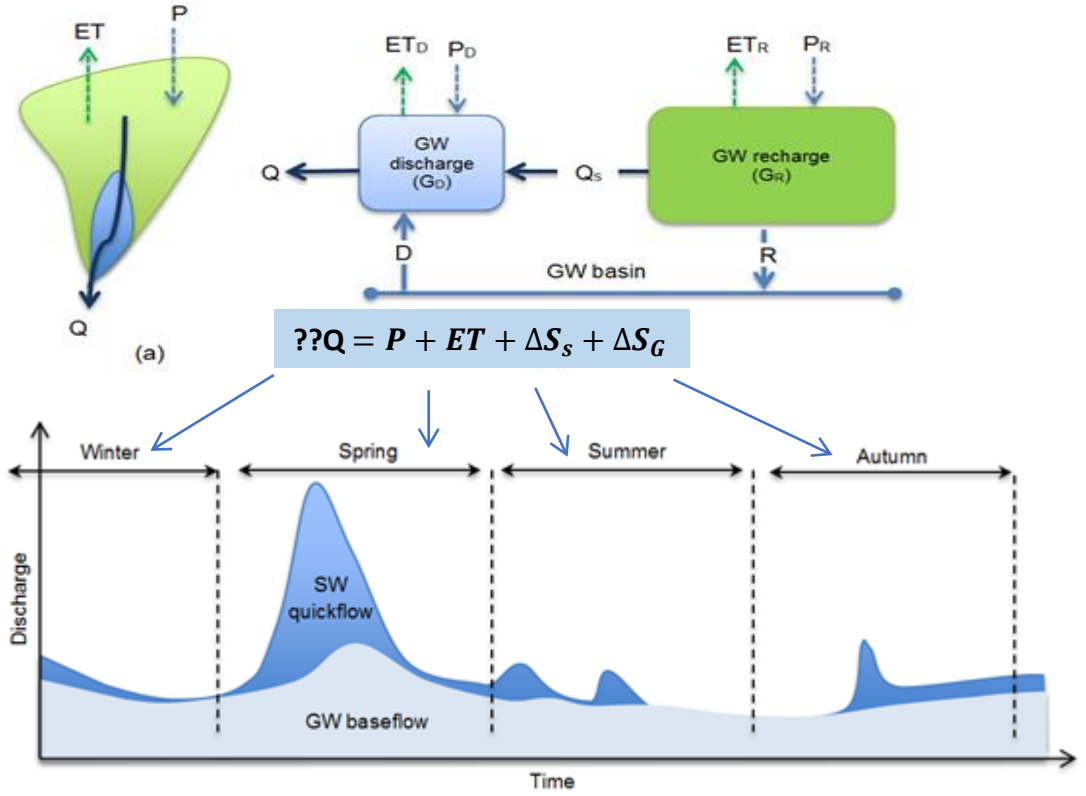


Figure 2: Ecosystems within a river basin that may be relevant to the achievement of the Directive's objectives (map chart)



Conceptual scheme of the SW runoff hydrograph with the SW and GW components, i.e. **quickflow** and **baseflow** correspondingly.
The hydrograph is based on visualisation of recorded SW runoff values at the SW gauging station over the certain time period.

The right schemes from: **INTERREG *WaterAct* Handbook manuscript**

Conclusion:

1. Related to the classification of the **Spring** ecosystems to the ***Lotic*** or ***Lentic ecosystems*** it can be said that there are many countries who try to apply presented classification in their country. However it seems that because of hydro-geological and other Country's specifics, different **spring ecosystems** at the first needed to be recognised, their feeding systems need to be described and corresponding notes to the **integrated national water database** added.
2. On the base of publication of springs restoration of arid zones the grazing, recreation and the road network are the biggest disturbances for the GDEs. In that case the most used restoration methods were creation of barrier or protection constructions, re-vegetation and channel reconstructions. However **Restoration** of GDEs is a complex action and is very much site or area specific. Therefor any kind of restoration activity should start from corresponding **planning actions**.
3. Followed to date the recommendations of the Water Framework Directive (WFD) does not support the fully integration of groundwater dependent ecosystems (**GDEs**) to the surface water "**water body" (WB)** systems; there is no **GDEs description criteria for the surface WBs,** except: "**connection to groundwater bodies**" in *Hydromorphological elements supporting the biological elements* in **1.1. Quality elements for the classification of ecological status.**

Thank You for your attention!

bit.ly/WaterAct-project

bit.ly/WaterAct-Researchgate

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REPUBLIC OF ESTONIA MINISTRY OF THE ENVIRONMENT

Nature Conservation Agency Republic of Latvia

TALLINN UNIVERSITY

REPUBLIC OF ESTONIA ENVIRONMENT AGENCY

UNIVERSITY OF LATVIA

GEOLOGICAL SURVEY OF ESTONIA

VIDZEME THE ONLY WAY IS UP!

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WaterAct

Joint actions for more efficient management of common groundwater resources