

November 2023



**Draft for Public Comment**

# **Draft United Nations Framework Classification For Resources**

**Supplemental Groundwater Specifications**

**Prepared by the  
Groundwater Resources Working Group of the Expert Group on Resource  
Management**



## Contents

**Commented [A1]:** Would benefit from numbering of sections and sub-sections.

Introduction .....	4
Groundwater Overview .....	5
The Need for the Supplemental Groundwater Specifications .....	5
Groundwater and the Sustainable Development Goals .....	5
Socially Necessary Groundwater Projects .....	6
Scope .....	7
Terms and Definitions .....	8
Groundwater Sources and Products .....	8
General Scheme for Project Classification .....	9
Project Evaluation: Groundwater Categories and E, F, and G-Axis Scores .....	10
Environmental, Social, and Economic Viability – The E-Axis Score .....	10
Technical feasibility and Maturity – The F-Axis Score .....	20
Degree of Confidence in Groundwater Deliverability – The G-Axis Score .....	22
Groundwater Project Classes .....	28
Viable Groundwater Projects: E.A.1/E.B.1/E.A.1.1/E.A.1.2-F1-G1+G2 .....	28
Potentially Viable Groundwater Projects: E.A.2/E.B.2-F2-G1+G2 .....	28
Prospective Groundwater Projects: E.A.3/E.B.3/F3-G4 .....	28
Non-Viable Groundwater Projects: E.A.3/E.A.3- F4-G4 .....	28
Groundwater Production That Will Not Be Used: E.B.3.1-F1-G1+G2 .....	28
Aggregation of quantities .....	29
References .....	29

**EGRM Groundwater Resources Working Group (GRWG) 2019-2023**

GRWG Chair 2023: Peter van der Keur (Denmark)

GRWG Chair 2020: Kevin Parks (Canada)

GRWG Chair 2019: Marco Petitta (Italy)

**GRWG Members 2019-2023:**

Malis Absametov (Kazakhstan), Daniyar Chensizbaev (Kazakhstan), Henk Coetzee (South Africa), Narmina Garayeva (Azerbaijan), Klaus Hinsby (Denmark), Lucio Martarelli (Italy), Oleksii Netskyi (Ukraine), Dan Palombi (Canada), Kevin Parks (Canada), Sergii Paiuk (Ukraine), Marco Petitta (Italy), Manzoor Qadir (UNU-INWEH), Teodóra Szócs (Hungary), Peter van der Keur (Denmark), Natalia Vinograd (Russia), Magdalena Worsa-Kozak (Poland).

## Introduction

The United Nations Framework Classification for Resources (UNFC) is a ~~resource-\_\_project-based~~ and principles-based classification system for defining the environmental, ~~social~~-economic viability and technical feasibility of projects to develop resources (UNECE, 2013; UNECE, 2020). UNFC provides a consistent framework to describe the level of confidence of future resource quantities produced by the project. UNFC has been designed to meet, to the extent possible, the needs of applications pertaining to:

- ~~P~~Policy formulation based on resource studies.
- ~~d~~Decision-making/support on resource exploitation.
- ~~r~~Resource-management functions.
- ~~c~~Corporate business processes.
- ~~f~~Financial capital allocation.

## Groundwater Overview

Groundwater is found beneath the earth's surface within the cracks, pores, caverns, and ~~other openings~~ in rock, sediments, and soils. It is estimated that ~~groundwater makes up 99% of the earth's liquid water~~. Groundwater provides drinking water for as much as 50% of the world's population and over 40% of the water needed to grow food (UN, 2022).

~~Shallow groundwater is active in the water cycle and exchanges with surface water, terrestrial and aquatic ecosystems, and the atmosphere. In this mode it stays fresh and renewable, but it is also vulnerable to pollution and overuse threatening both drinking water resources and the ecological status of dependent and associated ecosystems. Deep groundwater circulates much slower and participates in the rock cycle and the water cycle. It has high mineral and salt content and requires treatment prior to use for non-saline requirements. Deep groundwater is not usually renewable on human time scales. Deep groundwater is used mainly for industrial water sources, energy production, and waste disposal.~~

~~While groundwater is abundant globally, it is highly variable across countries and regions. Groundwater supplies are diminishing in some regions, with an estimated 20% of the world's aquifers being over-exploited, suggesting groundwater use is often unsustainable. This trend needs to be reversed to ensure groundwater ~~is-remains~~ available as an essential water resource. Thus, it is critically important that this resource is developed and managed sustainably.~~

## The Need for Supplemental Groundwater Specifications

UNFC is designed to apply to all resource projects to enhance resource management and ~~make-inform~~ better decisions. Its generic specifications are meant to harmonize resource projects and quantity-reporting across diverse resource types. However, each resource has its own community of professionals with their own definitions and standards. The purpose of this Supplemental Groundwater Specifications document is to provide groundwater practitioners with technical guidance on how to apply UNFC to groundwater-~~resource~~ projects. The intended audience ~~-of these specifications are includes~~ resource managers and groundwater professionals who possess an appropriate level of expertise and relevant experience in the operation of groundwater projects and the estimation of groundwater quantity and quality.

## Groundwater and the Sustainable Development Goals

The key aspects of groundwater relevant to the Sustainable Development Goals (SDGs) of the 2030 Development Agenda are its use, management, and sustainability. Although ~~groundwater is inadequately referenced in the SDG~~

**Commented [A2]:** As used in the main UNFC document.

**Commented [A3]:** Is this reference needed? The latest UNFC supersedes previous versions.

**Commented [A4]:** This reference applies also to the rest of the paragraph, so should be moved at the end of it.

**Commented [A5]:** Would this include man-made structures, e.g., mines which are abandoned/flooded after the mining activity? Worth giving examples, particularly where they may overlap with other UNFC specifications.

**Commented [A6]:** Is this correct? Thus the water in the oceans, lakes etc is just 1% of the total volume of water

**Commented [A7R6]:** Some of the statistics quoted here appear to be at odds with those by [Groundwater Information on Earth's water \(ngwa.org\)](#), for example.

**Commented [A8]:** With or without processing? What is the definition of Ground water resource? Is 'fresh' part of the definition

**Commented [A9]:** Need to introduce what is 'shallow' and what is 'deep' in the subsurface context, as these terms may have different meanings in mining, oil & gas extraction, geothermal energy and storage projects.

**Commented [A10]:** It = shallow groundwater => thus Shallow ground water is always fresh => correct? Not in a ...

**Commented [A11]:** Wouldn't the previously mentioned food-growing also be under threat?

**Commented [A12]:** ? As? Examples?

**Commented [A13]:** geothermal and in that case deep-groundwater is not the product/resource but merely the ...

**Commented [A14]:** It is not clear how groundwater itself would be used for waste disposal; typically, there can be ...

**Commented [A15]:** Suggest expanding on what types of waste discharges to groundwater. In doing so, recommen ...

**Commented [A16]:** The approach of shallow vs. deep appears to overlook situations of vertical and lateral ...

**Commented [A17]:** Is this for quantity, availability/accessibility, or quality? Appears to be quant ...

**Commented [A18]:** The term aquifer has not yet been introduced.

**Commented [A19]:** Believe this is taken from [Why care about supply chain water risks? | Engagement guide | PR](#) ...

**Commented [A20]:** This paragraph would be better placed under section below on Groundwater and the ...

**Commented [A21]:** Better from which point of view? More sustainable? More equitable? More profitable?

**Commented [A22]:** What about all the other stakeholders of the UNFC?

framework – mentioned only once at the SDG target level (SDG 6.6 on water-related ecosystems) – it has several direct and indirect connections with the SDGs. Of the 169 SDG targets, there are 53 targets having interlinkages with groundwater use, management, and/or sustainability (Guppy et al., 2018). Thus, it is crucial to draw synergies between the SDG targets and groundwater allowing for results to be leveraged. About one-third of the interlinkages are 'mixed', suggesting that careful consideration must be given to possible impacts on groundwater from different perspectives to avoid unintended, adverse outcomes when the target activities are planned.

Although groundwater literature globally is substantial, project and resource quantity and quality data to support decision making on the path to the Sustainable Development Goals is not readily available.

### Socially Necessary Groundwater Projects

An innovation in the Supplemental Groundwater Specifications is the inclusion of a new sub-category of projects and associated quantities termed “socially necessary”. UNFC has traditionally been oriented towards classification of mineral and energy projects and associated quantities that are developed in a commercial framework. Sources are identified, projects are proposed and matured to commercial feasibility, and products are generated and sold or traded in the general economy. Direct impacts to the environment, especially in the subsurface, tend to be local. Ownership and access to the source tends to be clear and enforceable. Conflicts between project owners accessing a typical mineral resource tend to be uncommon and are mitigated by regulation or legal remedies. But given competing uses of subsurface resources including groundwater e.g., for a net-zero society, the resources-society-nature nexus and telecoupled systems must be taken into account to ensure sustainable resource-use considers the UN Sustainable Development Goals and Planet or Earth System Boundaries (SIWI, 2023, Luetkemeier, et al., 2021; Rockström et al., 2023).

Groundwater differs from static mineral and petroleum-types of mineral and energy-resource developments in important ways. Groundwater resources represent “common-pool resources” that can be accessed by all, with barriers to access that are costly and generally not enforceable. In a common-pool resource situation, individual actions in one’s best interest can lead to collective harm to all because harmful impacts are cumulative and widespread. Moreover, groundwater access can be viewed through the lens of human rights and be rooted in tradition and historical use, indigenous rights, property rights, and water law. Furthermore, because of groundwater’s role in the larger hydrosphere, its management is important to both the local environment and the Earth’s global circulation of water and essential elements. The environment itself becomes a stakeholder in groundwater projects.

To help manage this complexity, the UNFC Supplemental Groundwater Specifications introduces a category of groundwater projects termed “Socially Necessary Groundwater Projects”. The details are embedded in the text below. The motivation for this innovation is twofold. One is to recognize that many groundwater projects already exist outside of the commercial space of Earth-resource developments. These projects need to be recognized when assessing a proposed or existing groundwater project under UNFC. This will help ensure that the benefits and impacts of the new project are congruent with the prior existence and persistence of this class of projects. Without direct acknowledgement of their ongoing access to the common groundwater source, a “tragedy of the commons” event becomes possible.

The second motivation for recognizing this class of project is to generate data necessary to consider better overall governance of the groundwater resource, to protect the environment and the traditional users while capturing the stream of economic benefits from larger projects in a sustainable way and considering competing uses. By giving these projects their own category, their existence moves them out of the hydrological shadows and into a formal

**Commented [A23]:** Recommend checking this again, as groundwater is mentioned also in 6.3.2. ([Indicator 6.3.2 | UNEP - UN Environment Programme](#)), for example.

**Commented [A24]:** ?

**Commented [A25]:** This appears to be also from Guppy et al., 2018 - should be referenced again.

**Commented [A26]:** Compared to what?

**Commented [A27]:** This statement conflicts with the current definitions of E categories in the UNFC, where E already defines environmental, social and economical viability of projects. In addition, guidelines on Social & environmental considerations and on Social & environmental considerations: Principles of resource classification have already been produced, see [ECE ENERGY GE.3 2021 6e.pdf \(unece.org\)](#) and [ECE ENERGY GE.3 2020 3e.pdf \(unece.org\)](#).

**Commented [A28]:** What is the 'source' here?

**Commented [A29]:** ?

**Commented [A30]:** Resource here, was source two lines earlier?

**Commented [A31]:** ?

**Commented [A32]:** This whole section seems disconnected from the previous (unsupported) statement and is also very unclear.

**Commented [A33]:** This statement is in contradiction with water rights legislation in several countries. Groundwater CAN be privately owned.

**Commented [A34]:** these are all E-axis issues and thus can be catered for. They are not unique to groundwater but to all resources. The interference of groundwater resource projects or resource projects targeting the same aquifer at a location is also not unique to ground water but indeed valid for all type of resources.

**Commented [A35]:** E-axis issue

**Commented [A36]:** This is a strict interpretation of commercial only taking into account financial issues. E-axis issues are much broader and can include the necessary social elements mentioned above. Which means that a non-commercial project which is operating in is essence viable.

**Commented [A37]:** ?

structure for their benefit and for the benefit of new projects to be evaluated under UNFC. It will be incumbent on the UNFC evaluator to generate, estimate, or capture data regarding this class of project when completing a UNFC assessment. The stakeholders represented by this class will probably not have the motivation, requirement, or technical ability to participate in this type of assessment for their own project. Government resource-inventories may help, but further analysis should be expected to meet the goals of a UNFC project assessment as described herein.

## Scope

This document specifies functional requirements to classify groundwater projects according to UNFC, including:

- a) Project categorization
- b) Project classification
- c) Project aggregation

It does not describe techniques in detail, nor does it specify methodologies for the individual phases.

## Normative References

This document is supplementary and subject to the United Nations Framework Classification for Resources Update 2019, UNFC 2019 for short (UNECE, 2020). UNFC 2019 is an update of the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 Incorporating Specifications for its Application (UNECE, 2013). UNFC 2019 includes generic specifications for the application of UNFC. These Supplemental Groundwater Specifications shall be applied in a manner consistent with these generic specifications.

The following referenced documents provide additional guidance for selected aspects of project classification. The latest edition of the referenced document (including any amendments) applies. Full references are given at the end of this document.

- Guidance Note to Support the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 Definition of a Project (EGRM, 2016).
- Guidance Note on Competent Person Requirements and Options for Resources Reporting (EGRM, 2017a).
- Guidance Note to Support the United Nations Framework Classification for Resources Specification for Evaluator Qualifications (EGRM, 2017b).
- Guidance for Social and Environmental Considerations for the United Nations Framework Classification for Resources (EGRM, 2021).

## Guidelines on the Application of Key Instructions in UNFC

UNFC Part II Annex III applies. In these specifications, the following words have specific meanings:

- "Shall" is used where a provision is mandatory.
- "Should" is used where a provision is preferred.
- "May" is used where alternatives are equally acceptable.

Generic specifications as defined in UNFC 2019 sets a minimum standard for reporting under UNFC.

**Commented [A38]:** Is this suggesting that the UNFC is going to be extended beyond the present scheme? Alignment with UNFC categories is to be maintained as these specifications are not meant to exist as stand-alone.

**Commented [A39]:** Given that the E axis of the UNFC already accounts for social and environmental feasibility of projects, what is this new proposed category going to do and how will it relate to the socio-environmental viability to be already assessed under E1-2-3, without causing double-counting of the same aspects?

**Commented [A40]:** ?

**Commented [A41]:** ?

**Commented [A42]:** How are classification and categorization different in UNFC?

**Commented [A43]:** What phases?

**Commented [A44]:** These have been superseded by [ECE/ENERGY/GE.3/2022/4 \(unece.org\)](https://unece.org/ECE/ENERGY/GE.3/2022/4)

**Commented [A45]:** Two guidance documents to be referred to: Guidelines on Social & environmental considerations and on Social & environmental considerations: Principles of resource classification, see [ECE ENERGY GE.3 2021 6e.pdf \(unece.org\)](https://unece.org/ECE/ENERGY/GE.3/2021/6e.pdf) and [ECE ENERGY GE.3 2020 3e.pdf \(unece.org\)](https://unece.org/ECE/ENERGY/GE.3/2020/3e.pdf).

## Terms and Definitions

UNFC includes a glossary of terms necessary for its application. Additional contexts for application of the Supplemental Groundwater Specifications are described below.

### Groundwater Sources and Products

UNFC classifies resource quantities as either **sources** or **products**. Sources represent the feedstock for projects. **Products** represent the output of the project that may be used, sold, or transformed into other products.

A groundwater source is any accumulation of naturally occurring and **freely moving** water found beneath the surface of the Earth. This includes all such water found in the pore spaces, voids, caverns, and fractures in igneous, sedimentary, and metamorphic rocks and in pores, fissures, and interstices in unconsolidated earth materials. It includes all groundwater regardless of chemical quality from fresh to highly saline, and with or without the presence of dissolved mineral salts, minor amounts of organic liquids like petroleum, dissolved gases, and natural or anthropogenic chemical contaminants. **Groundwater includes any surface water induced to flow into the subsurface due to groundwater development. This includes water wells and any other development, e.g. drainage galleries that are built structures having the purpose of extracting groundwater from a source for use as a product at surface.** Transference of groundwater from one subsurface source to another subsurface reservoir, for mitigating seawater intrusion for example, should also be considered a project linking a source to a product as long as there is intention to develop and there is a project per the UNFC definition.

Groundwater sources do not include:

- **Diversions of groundwater naturally discharging at the surface of the Earth at a spring or seepage face without connections to aquifers involved in groundwater projects.**
- Water passively collected at surface as at a dugout or natural body of surface water, even when those sources are known to be supplied by groundwater.
- Soil moisture found above the water table accessed by vegetation.
- **Water that condenses out of petroleum during its production.**
- **Water that purposely carries waste into subsurface storage or disposal zones.**
- Water that is chemically bound in mineral crystals.

A groundwater product is defined as liquid water extracted from below the surface of the Earth through a built structure, usually a water well. Produced groundwater is usually meant to be water supply for human sustenance, agriculture, or other beneficial use. Chemical or physical treatment is commonly needed to convert groundwater from the source to product for use. Water treatment should generally be considered as part of a groundwater development project, unless it is part of a larger water-treatment system that blends water from multiple sources including surface water.

Significant groundwater production is often linked to a purpose other than water supply. **Examples of this include co-production of saline groundwater during petroleum production and groundwater produced to dewater a mine or excavation.**

### Terms with Particular Meaning in UNFC

Some terms with particular meanings are used in the Category definition tables below.

**Commented [A46]:** This appears not to be correct. UNFC classifies projects, with product quantity estimates attached to projects. The source itself is not classified.

**Commented [A47]:** Isn't the resource the quantity of the product produced?

**Commented [A48]:** If the free water movement is driven by a recharge and discharge, need to define the charge and recharge terms too, and if those are separate from or part of the 'source' being defined here.

**Commented [A49]:** ?

**Commented [A50]:** Does this mean that the wells themselves are taken here as being part of the 'source', rather than being part of the 'project'?

**Commented [A51]:** Missing a definition of the product. Earlier it is suggested that it will be predominantly fresh water so the resource is fresh water which can be a smaller volume after treatment than the volume originally produced from the source as the waste stream (brine) is separated.

**Commented [A52R51]:** Missing clear definitions of:  
- source  
- resource  
- project  
in the groundwater context.

**Commented [A53]:** Unclear.

**Commented [A54]:** What about water that is co-produced by oil&gas wells, which was already in liquid water form in the reservoir? (mentioned below)

**Commented [A55]:** See earlier comment about the need for clarification of what is intended here for waste disposal in groundwater.

**Commented [A56]:** In addition to the previous remark, this definition can be made sharper: as mentioned earlier, the product is freshwater. The source is the groundwater / formation water, either fresh or saline. The product of a groundwater project is in general fresh water. The resource is the cumulative amount of product which is 'sold, transferred, used, unused or consumed in operations'.

**Commented [A57]:** In these specific cases there is no product which is sold. It is an interesting point that requires further thought. If using the Petroleum specifications, water in that case is not an unsold portion of the produced hydrocarbons; it's a different by-product altogether. It is similar to the case of lithium co-production in geothermal projects - the geothermal specifications state that "A Geothermal Energy Product is an energy product that is sold, used, or otherwise delivered by a Project associated with (at least) one Geothermal Energy Source. Examples of Geothermal Energy Products are electricity and heat (for Geothermal Heating and Cooling). Other products, such as inorganic materials (e.g., silica, lithium, manganese, zinc, sulphur), gases (e.g., carbon dioxide) or water without ...



**Foreseeable Future:** The period of time that a project can make a reasonable projection of the occurrence of future conditions, events or other factors that determine the environmental-socio-economic viability or technical feasibility of a project.

**Reasonable Expectations:** High level of confidence. This term is used within the E1 classification and concerns the likelihood that all necessary conditions will be met. It is used in the F1.3 sub-category and concerns the likelihood that all necessary approvals/contracts for the project to proceed to development will be forthcoming.

**Reasonable Prospects:** Moderate level of confidence. This term is used within the E2 and E3 classification and concerns the likelihood that all necessary conditions will be met.

**Reasonable Time Frame:** The time frame within which all approvals, permits and contracts necessary to implement the project are to be obtained. This should be the time generally accepted as the typical period required to complete the task or activity under normal or typical circumstances.

### General Scheme for Project Classification

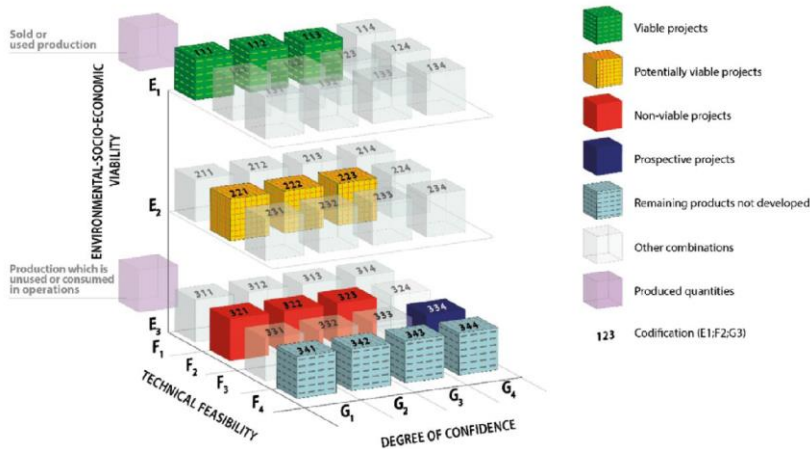
UNFC 2019 classifies resource projects based on three criteria: (i) environmental, social, and economic viability, (ii) technical feasibility and maturity, and (iii) confidence in the estimate of quantities to be produced by the project (Figure 1). These criteria are scored in a three-dimensional system with three axes called E, F, and G. The environmental, social, and economic viability score defines placement on the E-axis, the technical feasibility and maturity score defines placement on the F-axis, and confidence in quantities score defines placement on the G-axis. The generic scoring on the E, F, and G axes are set by predefined Categories in the UNFC. The Category score is represented by a number (e.g., E1, E2, etc.), where a lower score is more favourable for product development. Sub-categories are added when useful in describing differences that would not impact the axes score (e.g., E1.1, E1.2, etc.).

**Commented [A58]:** If these are applied here to groundwater as they are in UNFC, this section appears to be redundant.

**Commented [A59]:** No need to repeat sections of the UNFC as already is. This document should only outline Supplementary Specifications necessary for the Application of the UNFC to groundwater resources.

**Commented [A60]:** UNFC has an inherent hierarchical structure along the E-axis, for both categories and sub-categories (except perhaps for E3.1). Is this maintained in the current proposed E structure?

UNFC Categories and Examples of Classes



**Figure 1: Three-dimensional representation of the UNFC axes, categories, and classes** (ECE ENERGY SERIES No. 61).

The 3-part combinations of the E, F, and G-Category scores are used to define Classes and Sub-classes. The Classes are applied to resource projects and the quantities that are either available for development or are on production to succinctly describe the state of projects. The Classes allow a basis for comparison and aggregation of project quantities, forecast potential projects, and help identify barriers to desired development.

The UNFC recognizes combinations of E, F, and G-scores as Classes and Sub-classes. A subset of these is recognized as being particularly useful and are formally described in UNFC, but there are no restrictions on using any of the other E, F, and G sub-class combinations.

### Project Evaluation: Groundwater Categories and E, F, and G-Axis Scores

Groundwater projects have aspects that require supplemental specifications for E, F, and G categorization and scoring. The details are reported in the E, F, and G-tables below following the generic Category scoring system of the UNFC.

### Environmental, Social, and Economic Viability – The E-Axis Score

UNFC describes the E-axis of classification as the degree of environmental, social, and economic viability or acceptability. Another way to understand the E-axis is to consider it as a score on the degree to which externalities are satisfied, mitigated, or solved. Four aspects of groundwater development will condition the evaluation of the E-axis scores for groundwater projects in addition to those in the general specification of UNFC. These are:

- The degree of hydraulic connection or communication with surface water and ecosystems (terrestrial and aquatic) and the time scales across which these connections are active relative to human-time scales.
- The presence of mutual interference and cumulative effects of projects accessing the same source and the recognition that chemical quality of groundwater in the source can be altered by development.
- The presence of socially necessary, numerous but usually small projects in groundwater sources that otherwise may not meet ideal E, F, and G-axis technical constraints for development and yet are deemed viable due to their social value.
- The presence of non-groundwater projects that produce significant quantities of groundwater.

Hydrogeologists have created several frameworks to assess the long-term viability of groundwater projects considering above-mentioned aspects. These frameworks typically invoke a spectrum with endmembers. One typical endmember represents a water-well that can produce groundwater at a constant rate indefinitely because it has balanced its yield with the capacity of the environment to replace the water produced. Another typical endmember represents groundwater abstracted from a finite aquifer that has no capacity to be replenished, essentially creating a groundwater mine.

Cuthbert et al. (2022) offer a four-quadrant groundwater management framework of value to applying UNFC to groundwater projects. They recognize that groundwater projects reduce the store of groundwater near a pumping well in order to generate flow to the well. This reduction induces groundwater flux and further storage reduction that ultimately interacts with surface-water stocks and flows. The surface-water system in the radius of influence from the well will respond with increases in recharge and/or diversion of surface water to the groundwater system, and/or decreases in groundwater discharges to surface receptors found in the undeveloped system. The sum of increased recharge and decreased discharge is called the capture of the well.

For any given hydrogeological system, there will be a maximum amount of capture available. If pumping exceeds the maximum capture, the well will continue to deplete groundwater in storage. When the well stops pumping, the

**Commented [A61]:** But 'resources' and 'products' in the groundwater context have not been defined yet.

**Commented [A62]:** Are these E-axis issues? or do they more fit in the technical F-axis issues?

**Commented [A63]:** ?

**Commented [A64]:** As previously stated, E is not just a 'technical' (economic) axis.

**Commented [A65]:** ? examples of what these might be?

**Commented [A66]:** This section appears to be a piece of literature review that is not directly put in the context of UNFC nomenclature and principles.

**Commented [A67]:** what are 'endmember' in the context of UNFC? How do they relate to Project (e.g., as infrastructure) and or to recharge terms already adopted in UNFC renewables specifications?

capture will continue as the depleted groundwater stocks replenish. The response time for the groundwater stocks to replenish can be much greater than the duration of pumping. In the framework of Cuthbert et al. (2022), groundwater projects are divided into four classes: (1) projects wherein groundwater yields ( $Y$ ) are less than maximum capture available ( $Q_{max}$ ) and response times ( $t_r$ ) relative to timescales of human interest ( $t_h$ ) are rapid; (2) projects wherein groundwater yields are less than maximum capture available and response times are slow; (3) projects wherein groundwater yields are greater than maximum capture available and response times are rapid; and (4) projects wherein groundwater yields are greater than the maximum capture available and response times are slow.

Using Cuthbert et al. (2022) as a starting point and in presence of replenishment from adjacent aquifers, it is possible to propose the following classification. Project class (1) describes projects that have the potential to be physically sustainable because yields are less than maximum capture and renewable because storage depletion is rapidly replenished with respect to timescales of human interest. Project class (2) describes projects that have the potential to be physically sustainable but not renewable because storage depletion is permanent relative to timescales of human interest. Project class (3) describes projects that have the potential to be renewable on timescales of human interest, but not physically sustainable. Project class (4) describes projects that are neither physically sustainable or renewable on timescales of human interest and should be managed as groundwater mining or strategic depletion activity.

There are social and environmental thresholds built into this proposed classification scheme which make it amenable for use with the UNFC. The general scheme compares groundwater yield in a project to the maximum capture. It is important to note that the increase in recharge and decrease in discharge that comprise the capture may have detrimental social and environmental effects that become intolerable at rates of total capture less than the physically sustainable maximum. Furthermore, the reality of mutual interference and cumulative effects of groundwater projects in the same hydraulically continuous system, make the tolerable or physically sustainable maximum capture not necessarily available to all projects simultaneously. There may also be geotechnical and geological hazards associated with storage depletion that are socially or economically intolerable even if the resource is renewable. Lastly, the threshold for renewability depends on society's time horizon of interest and consideration of groundwater value in terms of meeting the needs of the present without compromising ecological integrity or the ability of future generations to meet their own needs. The authors of this framework suggest 50-100 years as a threshold of response time to separate renewable from non-renewable resources. The authors' also note that there can be impacts on the chemical quality of groundwater from a development, seawater intrusion for example. They note that a potential chemical quality limit on capture may be less than the physically sustainable limit, above which chemical degradation can occur even though maximum capture has not been exceeded. This affects renewability because the replenished stocks of groundwater may not be chemically equivalent as those initially pumped.

These UNFC Supplemental Specifications for groundwater recognize the complexity inherent in groundwater management as reflected in the framework of Cuthbert et al. (2022), and its published predecessors. Using the project classes introduced above, two schedules for categorization of the E-axis are presented (Table 1).

The primary schedule, Schedule E.A, (Table 2) applies to most groundwater projects. It will be adopted when yield is less than maximum groundwater recharge irrespective of the response time, and when yield exceeds the maximum groundwater recharge but response time of replenishment is compatible with timescales of human interest.

Schedule E.B (Table 3) applies only to groundwater-mining projects that are characterized by maximum capture rates approaching zero and response times much greater than the timescales of human interest. These projects involve groundwater extraction that have no expected interaction with surface water due to geology and/or depth and will

**Commented [A68]:** How does this relate to E-F-G classification in UNFC? In UNFC, 'A Class is uniquely defined by selecting from each of the three criteria a particular combination of a Category or a Sub-category (or groups of Categories/Sub-categories).' Is this an attempt to present the equivalent of FIGURE 2 Abbreviated Version of UNFC, showing Primary Classes in the UNFC document? A table would be helpful to the reader.

**Commented [A69]:** But the considerations summarised above from Cuthbert et al. (2022) encompass F and G aspects as well, not just E aspects.

**Commented [A70]:** what do 'schedules' correspond to in UNFC terms?

**Commented [A71]:** is zero the max?

not replenish except at geological time scales. Schedule E.B can also be considered when evaluating groundwater produced or co-produced in the extraction of deep underground petroleum, mineral, and geothermal resources and the development of underground storage space covered elsewhere by the UNFC system (e.g., injection, geothermal energy, petroleum).

**Commented [A72]:** unclear why the 'not replenish except at geological time scales' relates to geothermal energy projects. Recharge is indeed taken into consideration in the Supplementary Specifications for the application of the United Nations Framework Classification for Resources (Update 2019) to Geothermal Energy Resources.

**Commented [A73]:** Is this scheme not only valid when the mining project is producing groundwater and uses it as a resource. It then can be classified using the resource classification scheme. If it is not a resource attached to the mining project then it just waste unless regulation states that all groundwater co-produced irrespective whether it is put to use, should be regarded as resource and as such be classified. I do not see the benefit of introducing an additional table for these so-called groundwater projects

<p>Type 1 Projects</p> <ul style="list-style-type: none"> <li>• Yield (<math>Y</math>) &lt; Maximum Capture (<math>Q_{max}</math>)</li> <li>• Response time (<math>t_c</math>) &lt; Timescale of Human Interest (<math>t_h</math>)</li> <li>• Consult Schedule E.A</li> </ul>	<p>Type 2 Projects</p> <ul style="list-style-type: none"> <li>• Yield &lt; Maximum Capture (<math>Q_{max}</math>)</li> <li>• Response time (<math>t_c</math>) &gt; Timescale of Human Interest (<math>t_h</math>)</li> <li>• Consult Schedule E.A</li> </ul>
<p>Type 3 Projects</p> <ul style="list-style-type: none"> <li>• Yield &gt; Maximum capture (<math>Q_{max}</math>)</li> <li>• Response time (<math>t_c</math>) &lt; Timescale of Human Interest (<math>t_h</math>)</li> <li>• Consult Schedule E.A</li> </ul>	<p>Type 4 Projects where:</p> <ul style="list-style-type: none"> <li>• Yield &gt; Maximum capture (<math>Q_{max}</math>)</li> <li>• Response time (<math>t_c</math>) &gt; Timescale of Human Interest (<math>t_h</math>)</li> <li>• Consult Schedule E.A</li> </ul> <p>Type 4 Projects where:</p> <ul style="list-style-type: none"> <li>• Maximum capture (<math>Q_{max}</math>) = 0</li> <li>• Response time (<math>t_c</math>) &gt;&gt; Timescale of Human Interest (<math>t_h</math>)</li> <li>• Consult Schedule E.B</li> </ul> <p>Incidental or co-production of groundwater in extraction of deep underground petroleum, mineral, and geothermal resources, or development of deep underground storage reservoirs</p> <ul style="list-style-type: none"> <li>• Consult Schedule E.B, specifically class E.B.3.1</li> </ul>

**Table 1:** Linkage between type of groundwater project and appropriate schedule E to consult for E-axis categorization. Schedules E.A and E.B for the E-Axis are summarized in tables 2 and 3.

**Table 2.** E Axis – Environmental-Social-Economic Viability: Schedule E.A.

E Axis – Environmental-Social-Economic Viability: Schedule E.A.  
(See Table 1 for explanation)

Category	Definition	Supporting Explanation (UNFC 2019)	Additional Groundwater Context
E.A.1	Development and operation are confirmed to be environmentally-socially-economically viable.	Development and operation are environmentally-socially-economically viable based on current conditions and realistic assumptions of future conditions. All necessary conditions have been met (including relevant permitting and contracts) or there are reasonable expectations that all necessary conditions will be met within a reasonable timeframe and there are no impediments to the delivery of the product to the user or market. Environmental-socio-economic viability is not affected by short-term adverse conditions provided that longer-term forecasts remain positive.	<p>A groundwater project that demonstrates it will meet all social, environmental, and economic conditions for operation, or there are reasonable expectations that it will meet all these conditions within a reasonable timeframe.</p> <p>There will be no harmful and irreversible physical or chemical impacts expected in the groundwater source or in surface-water bodies that are in hydraulic connection with the project, either from the direct effects of operations or because of any long-lasting hydraulic effects that may persist beyond the project's end-of-life. This condition applies to the project both as a stand-alone operation and in consideration of the cumulative effects of all other existing and prior groundwater projects accessing the same source and whose hydraulic or chemical effects have not returned to a pre-existing condition.</p> <p>There will be no harmful and irreversible impacts in general on society, the environment, or the economy because of project operations or because of any long-lasting hydraulic effects that may persist beyond the project's end-of-life, either as a stand-alone project or in consideration of cumulative effects as noted above.</p> <p>No geological, geophysical, or hydrological hazards are worsened or introduced to an area due to the project operation, e.g., seismicity, land subsidence, or urban flooding.</p> <p>There will be no harmful or irreversible changes in chemical quality of the groundwater source or surface water bodies due to operations.</p> <p>All necessary permits and approvals from regulating agencies are in place, or there are reasonable expectations that these will be in place in a reasonable timeframe. Transboundary groundwater sources and transboundary surface-water bodies in hydraulic communication with the groundwater source have an additional layer of political and legislative viability. The details and the stability of transboundary governance arrangements need to be considered when assessing project viability under current and future conditions.</p> <p>For the case of groundwater projects necessary for human or agricultural sustainment and where groundwater governance is traditional, absent, silent, or purposely permissive, the groundwater project may be deemed socially and environmentally acceptable by local practice or community consensus and yet not meet general E.A.1 conditions. Refer to Sub-Category E.A.1.2.</p>

**Commented [A74]:** in a hierarchal system the E1.2 should fit in the description of E1. Phrasing? They are all producing projects (E1) for E1.1 all permits are in place at E1.2 not all permits are in place but it is tolerated

<p><b>E.A.2</b></p>	<p>Development and operation are expected to become environmental-ly-socially-economically viable in the foreseeable future.</p>	<p>Development and operation are not yet confirmed to be environmental-ly-socially-economically viable, but based on realistic assumptions of future conditions, there are reasonable prospects for environmental-socio-economic viability in the foreseeable future.</p>	<p>A groundwater project that has been proposed that is likely to proceed because impacts to any environmental, social, and economic limits or thresholds associated with planned yields and chemical-quality changes are not likely to be exceeded now or in the foreseeable future.</p> <p>This condition applies to the project both as a stand-alone operation and in consideration of all other existing and prior groundwater projects accessing the same source and whose hydraulic or chemical effects have not returned to a E.A.1-compliant state, and/or any surface-water bodies with a hydraulic connection to the project. These aspects are to be provisionally confirmed before project operations commence.</p> <p>The proposed use of the groundwater source is expected to be in alignment with culturally and environmentally acceptable uses as well as policy, regulation, or community practice. Regulatory approval and community acceptance are expected to be timely and no insurmountable objections are expected to arise from neighbouring projects or stakeholders. It is expected that all impacted property and communal rights to the groundwater source will be respected and/or dispute resolutions can be used to mitigate or compensate for collateral harms to non-owners of the project. The same applies to the benefits (benefit sharing) for the associated communities and stakeholders of the groundwater project.</p> <p>The chemical quality of the groundwater is likely acceptable for the proposed use either as-is or with application of affordable and proven treatment technology. The project is expected to protect groundwater sources from contamination or quality-degradation and be protected similarly by others during the project lifespan and foreseeable future. Treatment of the water for chemical quality is not expected to cause harm to other environmental outcomes e.g., by creating a deleterious waste stream.</p> <p>This category of project may apply to proposed groundwater projects that are delayed while the conditions necessary for environmental, social, or economic viability are likely to be reached in the groundwater source due to cessation of prior operations and restoration of the system to natural or acceptable baseline conditions.</p>
<p><b>E.A.3</b></p>	<p>Development and operation are not expected to become environmental-ly-socially-economically viable in the foreseeable future or</p>	<p>Based on realistic assumptions of future conditions, it is currently considered that there are not reasonable prospects for environmental-socio-economic viability in the</p>	<p>A groundwater project that is proposed but not likely to proceed under present or foreseeable circumstances for one or more of these reasons:</p> <p>There is insufficient information to determine future socio-economic viability, e.g., lack of data about other users of source, uncertainty about demand for product, insufficient information to determine if harmful impacts can be mitigated or prevented to stakeholders' satisfaction.</p>

	evaluation is at too early a stage to determine environmental-socio-economic viability.	foreseeable future; or environmental-socio-economic viability cannot yet be determined due to insufficient information. Also included are estimates associated with projects that are forecast to be developed, but which will be unused or consumed in operations.	<p>The project as proposed creates harmful or irreversible impact to the source itself, to surface water in hydraulic communication with the source, or to society, the environment, or the economy in general. This may be because the cumulative, yet reversible, hydraulic, and chemical effects of other existing and prior groundwater projects have not yet returned to a pre-existing condition or have placed the source into such a state of stress for now and for the foreseeable future that new development is not viable.</p> <p>The project has shown high sensitivity to climate-change stresses under plausible scenarios. If allowed to proceed, it may create harm to economic, environmental, or social outcomes that would become acute if these scenarios come to pass, even though they are otherwise acceptable under present conditions. Either more time needs to pass to provide stakeholders with the assurance that harmful climate-related circumstances are not likely to arise, or more information must be acquired to demonstrate that the harms are not likely to occur even if the scenario comes to pass.</p> <p>This category of project may apply to proposed groundwater projects that are halted because the conditions necessary for environmental, social, or economic viability cannot be reached in the groundwater source until there is cessation of prior operations or restoration of the system to natural or acceptable baseline conditions, neither of which may be achieved in the foreseeable future.</p>
Category	Sub-Category	Sub-Category Definition (UNFC 2019)	Additional Groundwater Context
E.A.1	E.A.1.1	<p>Development is environmentally-socially-economically viable based on current conditions and realistic assumptions of future conditions.</p> <p>Attention paid to frameworks addressing sustainability, resiliency, and climate-change adaptation (non-governmental frameworks).</p>	<p>This is a superior sub-category that applies particularly to projects that meet legal, social, economic, and environmental criteria that mark viability based on current and future conditions and on hydrological stationarity; plus, are designed to be particularly resilient, robust, and adaptable to scenarios of hydrological change, climate change, socio-political change, or other unforeseen circumstances above and beyond that which is required by regulatory, environmental, financial or other conventions.</p>

	<p>E.A.1.2</p> <p>Development may not be known to be environmentally-socially-economically viable based on current conditions and realistic assumptions of future conditions, but is made viable through government permits, subsidies and/or other considerations.</p>	<p>This sub-category is reserved for socially necessary groundwater projects. These are formal or informal groundwater projects for which not all the social and environmental conditions associated with E1 apply but which are permitted by authorities because of social conditions including tradition, necessity, and sustenance.</p> <p>This sub-category should be applied to small groundwater projects including household, communal, and small-farm water wells. These projects are usually assigned to the WASH sector of water development, which stands for household-scale safe water for drinking, sanitation, and hygiene.</p> <p>There may also be cases where the social need or established right of access to groundwater is deemed paramount to society and factors like environmental impacts and degree of communication with surface water or other users are deemed irrelevant, not governed, or environmental trade-offs are acceptable. These cases will be deemed viable by social fit, not analysis and should be assigned this subcategory of E.</p> <p>A project such as this may be also accepted as viable when governance is traditional, absent, silent, or permissive of these kinds of projects. This situation can occur when groundwater projects are necessary for human or agricultural sustenance, are very old, are part of accepted cultural or community practices, are embedded in property or water rights, are indigenous entitlements, or for which there is no other alternative for water supply.</p> <p>New groundwater projects must consider the prior existence and claim on the same or adjacent (shallow) groundwater resources from these socially accepted yet possibly ungoverned pre-existing projects.</p>
<p>E.A.2</p>	<p>No Sub-categories defined</p>	
<p>E.A.3</p>	<p>E.A.3.1</p> <p>Estimate of product that is forecast to be developed, but which will be unused or consumed in operations.</p>	<p>This category is applicable in cases where there are conflicts with most traditional and legal views of declaring a net beneficial use of groundwater before development. Unless this can be viewed as an input into another net beneficial use, the analyst must explain why project conditions require this category.</p>
	<p>E.A.3.2</p> <p>Environmental-socio-economic viability cannot yet be determined due to insufficient information.</p>	<p>A groundwater project that does not have sufficient information to determine social, environmental, or economic viability. This includes groundwater exploration and testing programs for which consideration of these aspects is out of scope.</p>



<b>E.A.3.3</b>	Based on realistic assumptions of future conditions, it is currently considered that there are not reasonable prospects for environmental-socio-economic viability in the foreseeable future.	Proposed, legacy, or operational groundwater projects that have potential to develop groundwater resources but also have known environmental and/or social constraints that will impede or prevent development in the present and under all foreseeable conditions.
----------------	---	---

**Table 3.** E Axis – Environmental-Social-Economic Viability: Schedule E.B

E Axis – Environmental-Social-Economic Viability: Schedule E.B. (See Table 1 for explanation)			
Category	Definition	Supporting Explanation (UNFC 2019)	Additional Groundwater Context
E.B.1	Development and operation are confirmed to be environmentally-socially-economically viable.	<p>Development and operation are environmentally-socially-economically viable based on current conditions and realistic assumptions of future conditions. All necessary conditions have been met (including relevant permitting and contracts) or there are reasonable expectations that all necessary conditions will be met within a reasonable timeframe and there are no impediments to the delivery of the product to the user or market.</p> <p>Environmental-socio-economic viability is not affected by short-term adverse conditions provided that longer-term forecasts remain positive.</p>	<p>A groundwater project that demonstrates it will meet all social, environmental, and economic conditions for operation, or there are reasonable expectations that it will meet all these conditions within a reasonable timeframe.</p> <p>There will be no harmful and irreversible physical or chemical impacts expected in the groundwater source from the direct effects of operations or because of any long-lasting hydraulic effects that may persist beyond the project’s end-of-life. This condition applies to the project both as a stand-alone operation and in consideration of the cumulative effects of all other existing and prior groundwater projects accessing the same source and whose hydraulic or chemical effects have not returned to a pre-existing condition.</p> <p>There be no harmful and irreversible impacts in general on society, the environment, or the economy because of project operations or because of any long-lasting hydraulic effects that may persist beyond the project’s end-of- life, either as a stand-alone project or in consideration of cumulative effects as noted above.</p> <p>No geological, geophysical, or hydrological hazards are worsened or introduced to an area due to the project operation, e.g., seismicity, land subsidence, or urban flooding.</p> <p>All necessary permits and approvals from regulating agencies are in place, or there are reasonable expectations that these will be in place in a reasonable timeframe. Transboundary groundwater sources in hydraulic communication with the groundwater source have an additional layer of political and legislative viability. The details and the stability of transboundary governance arrangements</p>

			<p>need to be considered when assessing project viability under current and future conditions.</p> <p>For the case of groundwater projects necessary for human or agricultural sustainment and where groundwater governance is traditional, absent, silent, or purposely permissive, the groundwater project may be deemed socially and environmentally acceptable by local practice or community consensus and yet not meet general E.B.1 conditions. Refer to Sub-Category E.B.1.2</p>
E.B.2	<p>Development and operation are expected to become environmentally-socially-economically viable in the foreseeable future.</p>	<p>Development and operation are not yet confirmed to be environmentally-socially-economically viable but, based on realistic assumptions of future conditions, there are reasonable prospects for environmental-socio-economic viability in the foreseeable future.</p>	<p>A groundwater project that has been proposed that is likely to proceed because impacts to any environmental, social, and economic limits or thresholds associated with planned yields and chemical-quality changes are not likely to be exceeded now or in the foreseeable future.</p> <p>This condition applies to the project both as a stand-alone operation and in consideration of all other existing and prior groundwater projects accessing the same source and whose hydraulic or chemical effects have not returned to a pre-existing condition, and/or any surface-water bodies with a hydraulic connection to the project. These aspects are to be provisionally confirmed before project operations commence.</p> <p>The proposed use of the groundwater source is expected to be in alignment with culturally and environmentally acceptable uses as well as policy, regulation, or community practice. Regulatory approval and community acceptance are expected to be timely and no insurmountable objections are expected to arise from neighbouring projects or stakeholders. It is expected that all impacted property and communal rights to the groundwater source will be respected and/or dispute resolutions can be used to mitigate or compensate for collateral harms to non-owners of the project. The same applies to the benefits (benefit sharing) for the associated communities and stakeholders of the groundwater project.</p> <p>The chemical quality of the groundwater is likely acceptable for the proposed use either as-is or with application of affordable and proven treatment technology. The project is expected to protect groundwater sources from contamination or quality-degradation and be protected similarly by others during the project lifespan and foreseeable future. Treatment of the water for chemical quality is not</p>

			<p>expected to cause harm to other environmental outcomes e.g., by creating a deleterious waste stream.</p> <p>This category of project may apply to proposed groundwater projects that are delayed while the conditions necessary for environmental, social, or economic viability are likely to be reached in the groundwater source due to cessation of prior operations and restoration of the system to natural or acceptable baseline conditions.</p>
<b>E.B.3</b>	<p>Development and operation are not expected to become environmentally-socially-economically viable in the foreseeable future or evaluation is at too early a stage to determine environmental-socio-economic viability.</p>	<p>Based on realistic assumptions of future conditions, it is currently considered that there are not reasonable prospects for environmental-socio-economic viability in the foreseeable future; or environmental-socio-economic viability cannot yet be determined due to insufficient information. Also included are estimates associated with projects that are forecast to be developed, but which will be unused or consumed in operations.</p>	<p>A groundwater project that is proposed but not likely to proceed under present or foreseeable circumstances for one or more of these reasons:</p> <p>There is insufficient information to determine future socio-economic viability, e.g., lack of data about other users of source, uncertainty about demand for product, insufficient information to determine if harmful impacts can be mitigated or prevented to stakeholders' satisfaction.</p> <p>The project as proposed creates harmful or irreversible impact to the source itself, to surface water in hydraulic communication with the source, or to society, the environment, or the economy in general. This may be because the cumulative, yet reversible, hydraulic, and chemical effects of other existing and prior groundwater projects have not yet returned to a pre-existing condition or have placed the source into such a state of stress for now and for the foreseeable future that new development is not viable.</p> <p>This category of project may apply to proposed groundwater projects that are halted because the conditions necessary for environmental, social, or economic viability cannot be reached in the groundwater source until there is cessation of prior operations or restoration of the system to natural or acceptable baseline conditions, neither of which may be achieved in the foreseeable future.</p>
<b>Sub-Category</b>	<b>E.B.3.1</b>	<p>Estimate of product that is forecast to be developed, but which will be unused or consumed in operations.</p>	<p>This category can be used to describe deep groundwater that is developed in conjunction with another resource type.</p>

Technical feasibility and Maturity – The F-Axis Score

Technical feasibility of a groundwater development entails the maturity of the technology proposed for the development as well as the degree of commitment from the project operator to invest, operate, and safely close the project. Groundwater developments involve substantial investments in hydrogeological characterization,

Commented [A75]: ?

engineering of extraction and monitoring, and groundwater treatment. The degree to which the technology is available and demonstrated for a given development and the degree to which an operator has demonstrated interest in pursuing the project account for the assessment scores on the F-axis.

Feasibility or maturity ladders commonly deployed in resource-extraction development include descriptive levels that can apply to groundwater projects, e.g., after Beale and Read (2013):

- Conceptual level – scoping study using historical records, public databases, published materials, field reconnaissance, test holes. Level of confidence is not yet estimated.
- Pre-feasibility – first-generation numerical models and production forecasting, site-specific testing and data gathering. Level of confidence qualitatively is stated as an even chance of success, i.e., as likely to succeed as not. Quantitatively this can be described as having a 50% (1/2) chance of technical success.
- Feasibility – Detailed planning including costing, monitoring site conditions for trends and variations. Second generation numerical models developed. The qualitative chance of success is expressed as being more likely to succeed than not. Quantitatively this can be described as having about a 67% (2/3) chance of technical success.
- Design and Construction – Site drawings, specifications, contracts, permits and then construction and installations. The project is technically almost certain to succeed at this point and financial and regulatory commitments are nearly secure. The quantitative chance of success can be described as about 90% (9/10).
- Operation – Production and maintenance. The level of technical confidence is now certainty, or 100%.
- Closure and Return – Removal of all subsurface equipment, sealing of boreholes, reclamation of the surface site. This aspect of project feasibility is not an explicit part of the UNFC but is often linked with regulatory approvals in formal projects before or during operation.

The chance factors at each level can be thought of as chance of success in a decision tree. These values can be linked to the volumes expressed by the G-axis for probability-weighted aggregation of quantities.

The Supplemental Groundwater Specifications for the F-Axis are summarized in Table 4.

**Table 4.** F Axis – Technical Feasibility and Maturity

F Axis – Technical Feasibility and Maturity			
Category	Definition	Supporting Explanation (UNFC 2019)	Additional Groundwater Context
F1	Technical feasibility of a development project has been confirmed.	Development or operation is currently taking place or sufficiently detailed studies have been completed to demonstrate the technical feasibility of development and operation. A commitment to developing groundwater should have been or will be forthcoming from all parties associated with the project, including governments.	<p>Groundwater production is currently prepared or underway. All technologies employed in production and treatment are proven.</p> <p>Wells are productive and groundwater chemical quality is acceptable or treatable.</p> <p>Sufficient technical studies have been completed to confirm that the project is and will remain technically feasible for the project lifetime.</p> <p>The project has the ongoing financial commitment of the operator and the satisfaction of regulators</p>

**Commented [A76]:** ? Under G, quantities may be estimated using deterministic or probabilistic methods (does not have to be probabilistic). Also, how does aggregation apply to single-project level?

			<p>necessary to safely operate the project for its intended lifetime, or such commitment is forthcoming.</p> <p>The chance of technical success is almost certain or 90% (9/10) before operation commences. The chance of success rises to 100% when operational.</p>
<b>F2</b>	Technical feasibility of a development project is subject to further evaluation.	Preliminary studies of a defined project provide sufficient evidence of the potential for development and that further study is warranted. Further data acquisition and/or studies may be required to confirm the feasibility of development.	<p>Feasibility studies using site-specific samples, data, and performance tests. These elements inform and confirm that technical recovery of groundwater is feasible, but additional evaluation under site-specific conditions may be warranted to get approval for project development and regulatory approvals.</p> <p>The chance of technical success is more certain than not, or about 67% (2/3).</p>
<b>F3</b>	Technical feasibility of a development project cannot be completely evaluated due to limited data.	Very preliminary studies of a project indicate the need for further data acquisition or study to evaluate the potential feasibility of development.	<p>Conceptual to pre-feasibility studies conducted by using limited information and data on record from surface water features, geophysical measurements, or other wells in the same or analogous aquifer indicate the need for further data acquisition. Pre-feasibility studies based on site-specific data not possible due to few or no data from the project site.</p> <p>The chance of technical success or failure is equally probable or about 50% (1/2).</p>
<b>F4</b>	No development project has been identified.	Remaining quantities of product not developed by any project. These are quantities which, if produced, could be bought, sold, or used (e.g., electricity and heat,).	<p>Groundwater in the target formation or aquifer cannot be extracted using currently existing technology, development, or exploitation methods.</p> <p>Groundwater in the target formation can be extracted but for which no plans exist to develop the source from projects with an F1, F2, or F3 score.</p> <p>No technology is foreseeable that would make recovery feasible, and no efforts are underway to develop technology that overcomes these limits.</p> <p>No chance of technical success can yet be assigned.</p>

#### Degree of Confidence in Groundwater Deliverability – The G-Axis Score

The UNFC G-Axis score is intended to convey the level of confidence in the estimate of quantities expected from a development project. In the UNFC system, the E-F score couplet of a project will be unique at a given time. The G-axis differs in that project quantities are simultaneously described by three quantities labeled as G1, G2, and G3.

**Commented [A77]:** As source, resource and product are still to be defined unambiguously in the groundwater context, it is unclear what quantities these are.

**Commented [A78R77]:** Under UNFC, these should be quantities of products from the project:

- (a) Produced quantities that have been sold or used. This would include direct domestic use of a solar home installation, or non-sales domestic supply of a product to a local market.
- (b) Produced quantities which are unused or have been consumed in operations.
- (c) Quantities of a known product that may be produced in the future. Technical and environmental-socio-economic evaluation studies based on projects constitute the basis for the classification.
- (d) Remaining quantities of product not developed by any project.
- (e) Quantities of a product that may be produced in the future from prospective projects. Technical and environmental-socio-economic evaluation studies based on prospective projects constitute the basis for the classification.
- (f) Remaining quantities of product not developed by any prospective project.

**Commented [A79]:** ?

It is common practice to associate these labels with parts of a probability distribution, where G1 represents the quantity with a 10% probability of being less than, or the P<sub>10</sub>; G2 represents the quantity with 50% probability of being either less than or greater than, or the P<sub>50</sub>; G3 represents the quantity with a 90% probability of being less than that value, or the P<sub>90</sub>. Note that some systems use a greater-than convention wherein G1 corresponds to P<sub>90</sub> and G3 corresponds to P<sub>10</sub>. If probabilistic scores are used, they can be used in conjunction with confidence-levels (chance of success) in a decision-analysis framework for portfolio and investment management and optimization.

**Commented [A80]:** Under G, quantities may be estimated using deterministic or probabilistic methods

In qualitative terms, G1 represents the low case (high confidence) estimate, G2 represents the best or most likely estimate, and G3 represents the high case (low confidence) estimate.

G1-G2-G3 triplets should be based on site-specific evidence and correspond to pre-feasibility studies according to the discussion above regarding F levels. When there is no site-specific evidence, such as at the conceptual level of project maturity, a single qualified estimate of quantities can still be provided, which is categorized as G4 in UNFC. If there is regional knowledge or analogs that can inform a possible range of quantities in probabilistic terms, these can be expressed as G4.1 for P<sub>10</sub>, G4.2 for P<sub>50</sub>, and G4.3 for P<sub>90</sub> estimates. A qualified evaluator would recognize that the range of variability of a G4.1-G4.2-G4.3 triplet should be greater than a project-specific range expressed as G1-G2-G3 values for projects with F-scores of 1, 2, or 3. Moreover, it should be expected that the span of uncertainty in the G1-G2-G3 estimate should decrease as project maturity increases and confidence levels rise per the F-axis, i.e. from F3 to F1.

Groundwater project G-scores should be applied to three aspects of the project: (1) total volume being extracted over the design life from storage and from capture, (2) rate at which groundwater can be produced from the well over the design life, and (3) range of chemical quality to be expected from the well over the design life. Any trends in these quantities should be noted and their ranges should be considered in light of the type of projects introduced above per the E-axis. It is possible to then compare the expected quantity and quality of groundwater to probabilities of exceedances of thresholds on tolerable capture and physical sustainability, renewability, and chemical-quality preservation.

**Commented [A81]:** ?

**Commented [A82]:** does this mean three different sets of G1-G2-G3 (or G4.1-G4.2-G4.3) for the same project, to encompass these three different aspects?

**Commented [A83]:** The product has an embedded quality definition, so if the produced groundwater cannot meet those standards (with or without treatment) than it is not a product and therefore there is no resource.

Factors that influence an evaluator's confidence in the deliverability of a groundwater project can include:

- Long-term performance records including volumes and flow rates from wells.
- Continuous recording of water levels and chemistry in producing and monitoring wells on site.
- Independent monitoring of changes to water, land, and ecosystems, through means like remote sensing.
- Climatic stationarity or resilience in face of possible climate change.
- Complexity of hydrogeological and geological conditions at the site is adequately understood.
- Evidence for the absence of induced geological hazards from groundwater extraction.
- Establishment of well-founded predictive hydrogeological explanation(s) for performance and monitoring observations, supported by successful calculations, numerical simulations, or machine-learning methods.
- In the absence of a single hydrogeological explanation for performance and observations, a well-founded ensemble of alternative explanations useful to minimize risk of deliverability failure under uncertainty.
- Geostatistically validated and accurate data of hydraulic and geological properties useful in project design, operations, and prediction.
- Fit-for-purpose, site-specific investigation, and tests to improve performance predictions.

The Supplemental Groundwater Specifications for the G-Axis are summarized in Table 5.

Table 5. G Axis – Degree of Confidence

G Axis – Degree of Confidence			
Category	Definition	Supporting Explanation (UNFC 2019)	Additional Groundwater Context
G1	Product quantity – low case.	Product quantity estimates may be categorized discretely as G1, G2 and/or G3 (along with the appropriate E and F Categories), based on the degree of confidence in the estimates (high, moderate, and low confidence, respectively) based on direct evidence. Alternatively, product quantity estimates may be categorized as a range of uncertainty as reflected by either (i) three deterministic scenarios (low, best and high cases) or (ii) a probabilistic analysis from which three outcomes (P <sub>90</sub> , P <sub>50</sub> and P <sub>10</sub> [or vice versa using the P <sub>10</sub> , P <sub>50</sub> , P <sub>90</sub> convention] are selected. In both methodologies (the “scenario” and “probabilistic” approaches), the estimates are then classified on the G Axis as G1, G1+G2 and G1+G2+G3, respectively. In all cases, the product quantity estimates are those associated with a project. Note: The G axis Categories are intended to reflect all significant uncertainties (e.g., source uncertainty, geologic uncertainty, facility efficiency uncertainty, etc.) impacting the estimated forecast for the project. Uncertainties include variability, intermittency and the efficiency of the development and operation (where relevant). Typically, the various uncertainties will combine to provide a full range of outcomes. In such cases, categorization should reflect three scenarios or outcomes that are equivalent to G1, G1+G2 and G1+G2+G3.	The G1 Degree of Confidence represents the low case or P <sub>10</sub> greater-than estimate in quantities. This degree of confidence is not recommended for use in groundwater projects in these Supplemental Specifications, but an operator may find it useful. If used, the project operator should provide an explanation.
G1+G2	Product quantity – best case.	Preliminary studies of a defined project provide sufficient evidence of the potential for development and that further study is warranted. Further data acquisition and/or studies may be required to confirm the feasibility of development.	The G1+ G2 Level of Confidence represents a moderate level of confidence or a best estimate for a groundwater project’s total volume, rate of production, and chemical quality during the project lifetime. The best estimate may be represented by the P <sub>50</sub> value of a statistical distribution of possible values.



			<p>It is recommended that the G1+G2 level of confidence be applied to groundwater projects. This is level of confidence represents the most likely value of the quantities for total volume, rate of production, and chemical quality in a project. This estimate supports design of project infrastructure and permitting in that the chance of introducing undersizing errors associated with using G1 estimates, and oversizing errors associated with using G1+G2+G3 estimates are minimized. This is important because groundwater projects tend to be non-commercial and thus have limited budget flexibility. Using the G1+G2 level of quantity assessment is also critical for consistent aggregation and reporting of volumes, as explained elsewhere in these Specifications.</p> <p>For a groundwater project, a high-quality best-estimate should be based on data from one or more test wells and ongoing field observations at the site. Monitoring-well data should be available for the test wells and for the production wells.</p> <p>Other considerations for inclusion in a high quality, best-estimate of groundwater quantities include:</p> <ul style="list-style-type: none"> <li>• If the hydrogeology at the site is heterogeneous, it should be well described. The aquifer should be mapped even though uncertainties might remain about its boundaries and/or its location within the host groundwater flow-system.</li> <li>• There can be alternative conceptual understandings of the site hydrogeology that explain available data and observations. If this is the case, then the possibility should exist to monitor, collect field data, or perform tests to eliminate reduce uncertainty that may lead to project failure and thereby improve the quality of the best estimate.</li> </ul>
--	--	--	---

**Commented [A84]:** Chemical quality is defined by the product. If it does not match that. it is not a resource anymore and the quantity is 0 or the project awaits techniques to process it to the required standard (hence, an F4), or it may that the present techniques are too expensive and as such the E classification ends up as E3

			<ul style="list-style-type: none"> <li>• The best estimate should be supported by a predictive model of the project for each alternative conceptual understanding. These models can be conceptual, process based, analytical, based on machine learning, or a combination. In all cases the predictions of the model will be reasonably matched by the field observations.</li> <li>• There should be sufficient data for the parameter heterogeneity in the calibrated models to be geostatistically characterized.</li> <li>• The forecasted chemical quality, rate of production, and total quantity of groundwater from the project might be at risk from climate change or geological accidents (e.g., seismicity) over the project's intended life span, but these risks are anticipated to be mitigated through design and operational considerations and not impact the best estimate.</li> </ul>
<b>G1+G2+G3</b>	Product quantity – high case.	Very preliminary studies of a project, indicate the need for further data acquisition or study to evaluate the potential feasibility of development.	The G1+G2+G3 Degree of Confidence represents the high case or P <sub>90</sub> greater-than estimate in quantities. This degree of confidence is not recommended for groundwater projects in these Supplemental Specifications, but an operator may find it useful. If used, the operator should provide an explanation.
<b>G4</b>	Product quantity associated with a Prospective Project, estimated primarily on indirect evidence.	A Prospective Project is one where the existence of a developable product is based primarily on indirect evidence and has not yet been confirmed. Further data acquisition and evaluation would be required for confirmation. Where a single estimate is provided, it should be the expected outcome but, where possible, a full range of uncertainty should be calculated for the prospective project. In addition, it is recommended that the chance of success (probability) that the prospective project will progress to a Viable Project is assessed and documented.	<p>A G4 level of confidence is applied when no direct information exists from a site on which to base an estimate of groundwater quantity or chemical quality for a project. In this case it is not prudent to assign a higher G-axis confidence interval. Estimates in this category are often made from historical or regional records.</p> <p>The G4 level of confidence may apply to situations where the target formation or aquifer at a site is promising for groundwater development, but there is not yet a test well or other points of direct observation to confirm estimates.</p>

			<p>There may also be indirect evidence that the target formation or aquifer at the site can deliver the desired chemical quality, rate of production, or total quantity of groundwater if a project existed. Indirect evidence that supports the prospect of groundwater development may include:</p> <ul style="list-style-type: none"> <li>● Past or current records of extraction of favourable chemical quality, rates of production, or total quantity in the target formation or aquifer at an analogous site, preferably inside the region of interest.</li> <li>● Local or regional hydrogeological mapping or modeling which suggests that chemical quality, rates of production, or total quantity over a project life in the target formation or aquifer inside the region of interest could fall within a desired target or range. When possible, the probability that this condition can be met should be assessed.</li> <li>● Local or regional geological or geophysical mapping indicating the presence of a promising target formation or aquifer and analogs elsewhere are documented to deliver groundwater production of favourable chemical quality, rates of production, or total quantity over a project's desired lifetime.</li> </ul> <p>If regional or analog information exists to give a range rather than a single G4 estimate, the evaluator may distinguish these values as G4.1-G4.2-G4.3, representing the low, best, and high case of estimate.</p>
--	--	--	---

## Groundwater Project Classes

Category scores in the UNFC E, F, and G-axes are combined as Classes and Sub-Classes to describe projects. The following Classes and Sub-Classes extend the generic UNFC Class definitions to convey the aspects of groundwater sources, products, and projects as captured in the E, F, and G-scores above.

### Viable Groundwater Projects: E.A.1/E.B.1/E.A.1.1/E.A.1.2-F1-G1+G2

A viable groundwater project is one that is producing groundwater in a continuing operation or has a reasonable expectation to be in operation. A key characteristic of a viable groundwater project is the presence of technical evidence, usually obtained through a historical record of performance, that the project will deliver the desired chemical quantity, quality, and production rate of groundwater for the project life.

As a recommended practice for groundwater-project evaluators, viable groundwater developments should be assumed to be in hydraulic communication with surface water unless there is evidence to the contrary. This will assure operators and stakeholders that the project meets or will meet all social, environmental, and economic conditions for operation. In cases that natural circumstances, such as the depth of the source, de-emphasize application of general surface environmental conditions then the schedule E.B applies.

In cases that social necessity for groundwater overcomes broader social, environmental, or economic considerations, a sub-category of E.A.1.2 applies. These are referred to as Socially Necessary Groundwater Projects to highlight their special considerations.

The degree of confidence in the quality, rate of production, or total quantity produced by a viable groundwater project should be quantified at the best estimate level, or G1+G2 category, as a general practice.

### Potentially Viable Groundwater Projects: E.A.2/E.B.2-F2-G1+G2

This Class includes groundwater projects that have been proposed, planned, or suggested as a future development opportunity by an operator. They have not yet satisfied all external requirements to demonstrate social, environmental, or economic viability or internal requirements of technical feasibility for an operator's investment and commitment. However, there are no apparent barriers to achieving this status in the foreseeable future.

### Prospective Groundwater Projects: E.A.3/E.B.3/F3-G4

This class includes groundwater projects for which a source is known, but for which development is hypothetical or in the distant future and for which no site data are available. There has been little to no study to support social, environmental, or economic viability or technical feasibility, operator investment or commitment. The evidence to support estimates of groundwater quality, rates of production, or total quantity is indirect.

### Non-Viable Groundwater Projects: E.A.3/E.B.3-F4-G4

This Class includes groundwater projects that are proposed or previously in operations that cannot meet the economic, social, or environmental thresholds needed to be permissible or cannot demonstrate technical feasibility and operator commitment needed for investment and operation. For the non-viable project, there are no foreseeable changes in the conditions which currently prevent development. It is possible that a pre-existing viable project has become non-viable for some reason, but its existence needs to be tracked until its hydraulic impacts are gone from the source.

### Groundwater Production That Will Not Be Used: E.B.3.1-F1-G1+G2

This Class includes projects where groundwater production can be incidental or necessary for other kinds of commodity projects, but not the focus for development. For example, this can be groundwater extracted for mine

Commented [A85]: why no G3 as well?

Commented [A86]: why no G3 as well?

Commented [A87]: this implies G4.1+G4.2. why no G4.3 as well?

Commented [A88]: same as above.

Commented [A89]: same as above.

dewatering, draining land for cultivation, dewatering soils for excavation, or co-produced during petroleum production.

### Aggregation of quantities

UNFC 2019 provides a framework for reporting of resource quantities in each Class in terms of their contribution to the total product already produced or available for development. These quantities are linked to the Classes described above plus two additional quantities: (1) Remaining products not developed from identified projects and (2) Remaining products not to be developed from prospective projects.

For evaluation of groundwater projects using UNFC 2019, it can be helpful to map these generic definitions into the broader view of reporting and aggregating groundwater resources familiar to groundwater professionals. There are complexities in reporting and aggregating groundwater quantities that stem from the renewable/non-renewable duality of groundwater resources and from groundwater relationships with surface water. It is vital to have these complexities clarified through a resource-inventory framework to properly assign categories, especially on the E-axis. Resource-inventory frameworks can bridge UNFC project-based aggregations of quantities to groundwater management units, aquifers, and transboundary aquifers.

To use UNFC 2019 for groundwater-quantity classification and reporting, it may be helpful for an evaluator to refer to the UN's System of Environmental Economic Accounting for Water, or SEEA-Water for short (United Nations, 2012), or a resource-accounting system of a similar nature in conjunction with these Supplemental Groundwater Specifications.

To account for cumulative effects on groundwater stocks and surface water stocks from future production, estimated quantities to be developed from more than one project will need to be added together or aggregated. UNFC 2019 recognizes the degree of confidence and uncertainty in these estimates through the G-Axis scores of projects. To aggregate uncertain groundwater quantities for reporting and analysis, the evaluator should use the best estimate (G1+G2) of the quantity or like estimate of expected value as determined from geostatistical analysis or other quantitative method. Expected values can be aggregated directly through simple summation. Confidence intervals will vary though, as reflected in the G-Axis scoring. Confidence intervals on aggregated expected values need to be generated statistically, e.g., through a Monte Carlo analysis.

Aggregation of expected values of future production and available stocks of groundwater and surface water may reveal a situation where permissible, sustainable, or safe limits of groundwater production are or will be exceeded. This situation is known as groundwater overdraft and may have the effect of converting otherwise Viable or Potentially Viable Groundwater Projects into Non-Viable Projects, now or in the foreseeable future. Aggregation and comparison to overdraft potential is an essential step for an evaluator to successfully apply UNFC to groundwater. Aggregation exercises should account for transboundary water agreements as well.

## References

Cuthbert, M.O., Gleeson, T., Ferguson, G., Bierkens, M. and Taylor, R., In review, 2022. Defining renewable groundwater use to improve groundwater management. <https://eartharxiv.org/repository/object/3348/download/6691>. Accessed February 26, 2023.

Expert Group on Resource Classification (EGRM), 2016. Guidance Note to Support the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 Definition of a Project. United Nations, Geneva.

Expert Group on Resource Classification (EGRM), 2017a. Guidance Note on Competent Person Requirements and Options for Resources Reporting. United Nations, Geneva.

Expert Group on Resource Classification (EGRM), 2017b. Guidance Note to Support the United Nations Framework Classification for Resources Specification for Evaluator Qualifications. United Nations, Geneva.

Expert Group on Resource Classification (EGRM), 2021. Guidance for Social and Environmental Considerations for the United Nations Framework Classification for Resources. United Nations, Geneva.

Guppy, L., Uyttendaele, P., Villholth, K. G., Smakhtin, V. 2018. Groundwater and Sustainable Development Goals: Analysis Of Interlinkages. UNU INWEH Report Series, Issue 04. United Nations University Institute for Water, Environment and Health, Hamilton, Canada

Luetskemeier, R., Söller, L., Frick-Trzebitzky, F., Hodžić, D., Jäger, A., Kuhn, D., 2021. Telecoupled groundwaters: New ways to investigate increasingly de-localized resources. *Water*, 13, 2906, <https://doi.org/10.3390/w13202906>

SIWI 2023. The essential drop to net-zero, unpacking freshwater's role in climate change mitigation. Report, <https://siwi.org/publications/essential-drop-to-net-zero-unpacking-freshwaters-role-in-climate-change-mitigation-report> - accessed 27-06-2023

United Nations Economic Commission for Europe (UNECE), 2013. United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 Incorporating Specifications for its Application. ECE Energy Series 42. United Nations, Geneva.

United Nations Economic Commission for Europe (UNECE), 2020. United Nations Framework Classification for Resources Update 2019. ECE Energy Series No. 61. United Nations, Geneva.

United Nations, 2022. The United Nations World Water Development Report 2022: Groundwater: Making the invisible visible. UNESCO, Paris. <https://unesdoc.unesco.org/ark:/48223/pf0000380721>

United Nations, 2012. System of Environmental Economic Accounting for Water (SEEA-Water). United Nations, New York. Beale, G. and Read, J. eds., 2013. Guidelines for evaluating water in pit slope stability. CSIRO Publishing.

Rockström, J., Gupta, J., Qin, D., Lade, S. J., Abrams, J. F., Andersen, L. S., Armstrong McKay, D. I., Bai, X., Bala, G., Bunn, S. E., Ciobanu, D., DeClerck, F., Ebi, K., Gifford, L., Gordon, C., Hasan, S., Kanie, N., Lenton, T. M., Loriani, S., ... Zhang, X., 2023. Safe and just Earth system boundaries. *Nature*. <https://doi.org/10.1038/s41586-023-06083-8>

United Nations Framework Classification for Resources, Update 2019, UNECE Energy Series No. 61; United Nations, Geneva, 2020