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Development, maintenance and implementation of the United Nations Framework Classification for Resources:
Groundwater Resources

Draft United Nations Framework Classification for Resources

Supplemental Specifications for Groundwater Resources

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

Summary

Groundwater is the water found beneath the earth's surface within the cracks, pores, caverns, and other openings in rock, sediments, and soils. The purpose of the United Nations Framework Classification for Resources (UNFC) Supplemental Specifications for Groundwater Resources is to provide groundwater practitioners with technical guidance on how to apply UNFC to groundwater-resource projects. The intended audience of these specifications is evaluators and groundwater professionals who possess an appropriate level of expertise and relevant experience in the operation of groundwater projects and the estimation of groundwater quantities.

The development of this document will take into consideration comments received from the Technical Advisory Group and feedback from the twelfth session of the Expert Group on Resource Management. This document incorporates the changes introduced by the recent update of UNFC (2019).

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Note: the country name indicates where the expert is located and not necessarily that the expert is representing the country.

Contents

I. Introduction

1. The United Nations Framework Classification for Resources (UNFC) is a resource-project and principles-based classification system for defining the environmental-socio-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 the future quantities produced by the project. UNFC has been designed to meet, to the extent possible, the needs of applications pertaining to:

- Policy formulation based on resource studies
- Resource-management functions
- Corporate business processes
- Financial capital allocation.

A. Groundwater Overview

2. Groundwater is the water 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 per cent of earth's liquid water. Groundwater provides drinking water for as much as 50 per cent of the world's population and over 40 per cent of the water needed to grow food.

3. Shallow groundwater takes active part in the water cycle and exchanges water with surface water and the atmosphere. In this way it stays fresh and renewable, but it is also vulnerable to pollution and overuse. Deep groundwater circulates much slower and participates in the rock cycle as well as the water cycle. It has high mineral and salt content and requires treatment prior to use. Deep groundwater is not usually renewable on human time scales. Deep groundwater is used for mainly for industrial water sources, energy production, and waste disposal.

4. While groundwater is abundant globally, it is highly variable across countries and regions. Groundwater supplies are diminishing in some regions, with an estimated 20 per cent of the world's aquifers being over-exploited, suggesting groundwater use is often unsustainable. Also, groundwater-quality deterioration is increasing. These trends need to be reversed to ensure groundwater sustainability as an essential water resource. Thus, it is critically important that this resource is developed and managed sustainably.

B. The Need for Supplemental Groundwater Specifications

5. UNFC is designed to apply to all resource projects to enhance resource-management and make better decisions. Its generic specifications are meant to harmonize resource project and quantity-reporting across diverse resource types. However, each resource has its own community of practicing professionals with their own definitions and standards. The purpose of this Supplemental Groundwater Resources 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 evaluators and groundwater professionals who possess an appropriate level of expertise and relevant experience in the operation of groundwater projects and the estimation of groundwater quantities.

C. Groundwater and the Sustainable Development Goals

6. 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 framework – mentioned only once at the SDG target level (SDG 6.6 on water-related ecosystems) – it has several direct and indirect interlinkages with SDGs. Of 169 SDG targets, there are 53 targets having

interlinkages with groundwater use, management, and/or sustainability. Thus, it is crucial to draw synergies between SDG targets and groundwater so that interlinkages allow leveraged results. 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.

7. Although groundwater literature globally is substantial and continues to grow, there is still a lack of well-structured, globally useful, up-to-date, and SDG-relevant groundwater-data availability. This may signal that all groundwater-related and groundwater-relevant aspirations may not be translated into real and measurable action. The adaptation of UNFC and these supplemental specifications for groundwater will support the generation of high quality, internally consistent, and globally comparable groundwater project and resource-quantity data to support decision-making on the path to attainment of the SDGs

D. Socially Necessary Groundwater Projects

8. 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 Earth 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 resource tend to be uncommon and are mitigated by regulation or legal remedies.

9. Groundwater differs from these types of Earth 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 as well as 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.

10. To help manage this complexity, the UNFC Supplemental Groundwater Specifications introduce 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. The first motivation is to recognize that very 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.

11. The other 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. By giving these projects their own category, their existence moves them out of the hydrological shadows and into a formal structure for their benefit and for the benefit of new projects to be evaluated under UNFC.

II. Scope

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

(a) Project categorization;

(b) Project classification;

(c) Project aggregation.

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

III. Normative References

14. This document is supplementary and subject to the United Nations Framework Classification for Resources Update 2019, UNFC (2019) (ECE Energy Series No. 41 and ECE/ENERGY/125). 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.

15. 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 (Expert Group on Resource Management, 2016)
- Guidance Note on Competent Person Requirements and Options for Resources Reporting (Expert Group on Resource Management, 2017)
- Guidance Note to Support the United Nations Framework Classification for Resources Specification for Evaluator Qualifications (Expert Group on Resource Management, 2017)
- Guidance for Social and Environmental Considerations for the United Nations Framework Classification for Resources (Expert Group on Resource Management, 2021).

IV. Guidelines on the Application of Key Instructions in UNFC

16. UNFC (2019) 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.

17. Generic specifications as defined in UNFC (2019) set a minimum standard for reporting under UNFC.

V. Terms and Definitions

18. UNFC (2019) includes a glossary of terms necessary for its application. Additional contexts for application of the Supplemental Groundwater Specifications are described below.

A. Groundwater Sources and Products

19. UNFC (2019) 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.

20. In the context of the Supplemental Groundwater Specifications, 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 rock as well as 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.

21. In the context of the Supplemental Groundwater Specifications, 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.

22. In the context of the Supplemental Groundwater Specifications, 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 usually needed to convert groundwater from the source to product water 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.

23. 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. Because of their significance to E, F, and G-scoring of groundwater projects, these non-supply groundwater projects are included in the Supplemental Groundwater Specifications in a Sub-class as allowed by UNFC.

B. Terms with particular meaning in UNFC

24. Some terms with particular meanings are used in the Category definition tables that follow.

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 also 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.

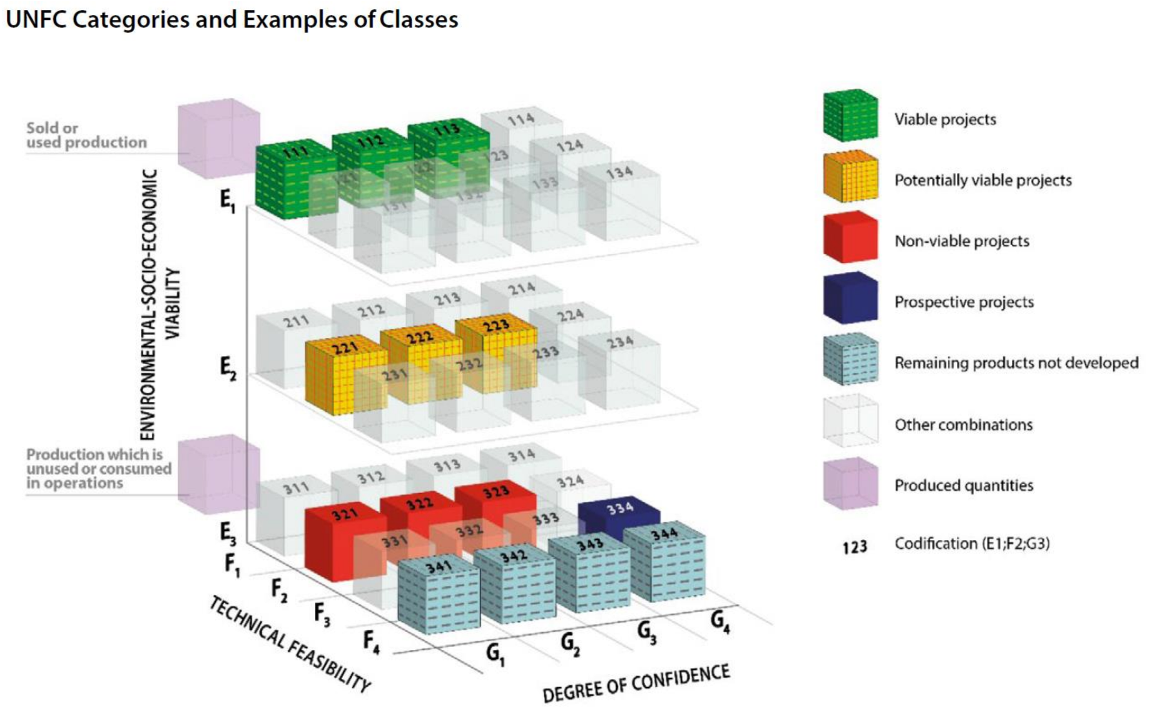
Reasonable Prospects: Moderate level of confidence. This term is used within the E2 and E3 classification and concerns the likelihood that all necessary conditions will be met.

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.

VI. General Scheme for Project Classification

25. UNFC (2019) classifies resource projects based on three criteria: (i) environmental-socio-economic viability, (ii) technical feasibility and maturity, and (iii) confidence in the estimate of quantities to be produced by the project (Figure I). 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 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 used when useful in describing differences that would not impact the axes score (e.g., E1.1, E.1.2, etc.).

Figure I
Three-dimensional representation of the UNFC Axes, Categories, and Classes



Source: From UNFC (2019) (UNECE, 2020).

26. 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 in order to succinctly describe the state of projects. The Classes allow a basis for comparison and aggregation of project quantities, to forecast potential projects, and help identify barriers to desired development.

27. 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 combinations if they are useful.

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

28. 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 that follow the generic Category scoring system of UNFC.

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

29. 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 (2019). These are:

- The degree of hydraulic connection or communication with surface water
- The presence of mutual interference and cumulative effects of projects accessing the same source
- 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.

30. The Supplemental Groundwater Specifications for the E Axis are as follows:

E Axis - Environmental-Social-Economic Viability			
Category	*Definition*	*Supporting Explanation (UNFC (2019))*	*Additional Groundwater Context*
E1	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.	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. 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. 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.

E Axis - Environmental-Social-Economic Viability			
Category	*Definition*	*Supporting Explanation (UNFC (2019))*	*Additional Groundwater Context*
			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. There will be no harmful or irreversible changes in chemical quality of the groundwater source or surface water bodies due to operations. All necessary permits and approvals from governing 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. For the case of projects accessing groundwater sources not in hydraulic communication with surface water, refer to Sub-category E.1.1. 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 E1 conditions. Refer to Sub-category E1.2.
E2	Development and operation are expected to become environmentally-socially-economically viable in the foreseeable future.	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.	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. 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

E Axis - Environmental-Social-Economic Viability			
Category	*Definition*	*Supporting Explanation (UNFC (2019))*	*Additional Groundwater Context*
			provisionally confirmed before project operations commence. The proposed use of the groundwater 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 will be respected and/or dispute resolutions exist that 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. 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 from same 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. 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.
E3	Development and operation are not expected to become environmentally-socially-economically viable in the	On the basis of 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-	A groundwater project that is proposed but not likely to proceed under present or foreseeable circumstances for one or more of these reasons: 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

E Axis - Environmental-Social-Economic Viability			
Category	*Definition*	*Supporting Explanation (UNFC (2019))*	*Additional Groundwater Context*
	foreseeable future or evaluation is at too early a stage to determine environmental-socio-economic viability.	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.	mitigated or prevented to stakeholders' satisfaction. 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 in not viable. The project has been proposed for a non-renewable source not in hydraulic communication with surface water, but for which the source cannot sustain the proposed yield because it would result in geotechnical harm to the subsurface or overlying land through subsidence, or there will be a socially unacceptable loss of the intergenerational value of the groundwater source. The proposed project may impact groundwater chemical quality resulting in harm to human health or the environment. There are no foreseeable ways to address these harms or there is insufficient information to demonstrate these harms will not happen. The project has shown high sensitivity to climate-change stresses under plausible scenarios of climate change. 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. 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

E Axis - Environmental-Social-Economic Viability			
Category	*Definition*	*Supporting Explanation (UNFC (2019))*	*Additional Groundwater Context*
			conditions, neither of which may be achieved in the foreseeable future.
E1	**E1.1**	Development is environmentally-socially-economically viable based on current conditions and realistic assumptions of future conditions.	This Sub-category will apply to groundwater projects for which not all the social and environmental conditions associated with E1 apply because of natural conditions. This Sub-category is normally applied to, but not restricted to, groundwater projects that extract groundwater from a source that is not in hydraulic communication with surface water and recharge areas due to hydraulically isolating geological layers or depth below the surface. Usually, these projects provide water for industrial purposes. For such projects, the groundwater source should be considered a non-renewable resource. All extractions will result in an irreversible reduction in groundwater storage. Despite this irreversible loss of groundwater in storage, the development would still be socially and economically viable. The non-renewable groundwater project still has some restrictions that determine viability. For example, it is viable when the stream of economic or social benefits resulting from groundwater production is greater than the loss of in-situ value of water-security, intergenerational bequest, and geotechnical services provided by the presence of groundwater such as avoidance of land subsidence or dilution of wastes disposed underground. In this category it is still essential that no geological hazards are worsened or introduced to an area due to the project operation, e.g., seismicity, land heave or subsidence. Though the source is not in hydraulic communication with surface water, its development may cause loss of groundwater storage and reduction in groundwater levels in other deep sources and this must also be considered when deeming a non-renewable project viable.
	E1.2	Development is not environmentally-socially-economically viable based on current conditions and realistic assumptions of future conditions	This Sub-category will apply to groundwater projects for which not all the social and environmental conditions associated with E1 apply because of social

E Axis - Environmental-Social-Economic Viability			
Category	*Definition*	*Supporting Explanation (UNFC (2019))*	*Additional Groundwater Context*
		but is made viable through government subsidies and/or other considerations.	conditions including necessity and sustenance. This Sub-category is normally applied to, but not restricted to, small groundwater projects including household, communal, and small-farm water wells. 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 or not governed. These cases will be deemed viable by social fiat, not analysis and should be assigned this Sub-category of E. A project such as this may be 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. 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. Groundwater projects that seek to develop non-renewable sources at depth below sources used by these ungoverned sources may need to address concerns of these projects and their stakeholders before they can reach a state of social viability even when their project has no environmental impacts except hydraulic changes in the source itself and produces a stream of economic benefits greater than the in-situ value.
E2	**No Sub-categories defined**		
E3	**E3.1**	Estimate of product that is forecast to be developed, but which will be unused or consumed in operations.	A non-groundwater project whose yield is produced incidentally to other kinds of resource projects, e.g., mine dewatering, produced water from energy wells, in the same source as the groundwater project. Its existence is outside the control of the groundwater project, but it needs to be

E Axis - Environmental-Social-Economic Viability			
Category	*Definition*	*Supporting Explanation (UNFC (2019))*	*Additional Groundwater Context*
			accounted for when assessing social, environmental and economic viability
	E3.2	Environmental-socio-economic viability cannot yet be determined due to insufficient information.	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.
	E3.3	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.

2. Technical feasibility and Maturity – The F-Axis Score

31. Technical feasibility of a groundwater development entails the maturity of the technology proposed for the development as well as the degree of commitment of the project operator to invest, operate, and safely close the project. Groundwater developments involve substantial investments in hydrogeological characterization, 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 the demonstrated interest in pursuing the project account for the assessment scores on the F axis.

32. The Supplemental Groundwater Specifications for the F Axis are as follows:

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 develop should have been or will be forthcoming from all parties associated with the project, including governments.	Groundwater production is currently prepared or underway. All technologies employed in production and treatment are proven. Wells are efficient and groundwater chemical quality is acceptable or treatable. Sufficient technical studies have been completed to confirm that the project is and will remain technically feasible for the project lifetime. The project has the ongoing financial commitment of the operator and the satisfaction of regulators necessary to safely operate the project for its intended lifetime, or such commitment is forthcoming
F2	Technical feasibility of a development project is subject	Preliminary studies of a defined project provide sufficient evidence of the potential for development and that further study is warranted. Further data	Site-specific samples, data, and performance tests exist. These elements inform and confirm that technical recovery of groundwater is feasible, but additional evaluation under site conditions may be

F Axis - Technical Feasibility and Maturity			
Category	*Definition*	*Supporting Explanation (UNFC (2019))*	*Additional Groundwater Context*
	to further evaluation.	acquisition and/or studies may be required to confirm the feasibility of development.	warranted to get sanction for project development and regulatory approvals.
F3	Technical feasibility of a development project cannot be 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.	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. Feasibility studies based on site-specific data not possible due to few or no data from the project site.
F4	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 (i.e., electricity, heat, etc., not wind, solar irradiation, etc.).	Groundwater in the target formation or aquifer cannot be extracted using currently existing technology, development, or exploitation methods. Groundwater in the target formation that can be extracted but for which no plans exist to develop the source from projects with an F1, F2, or F3 score. No technology is foreseeable that would make recovery feasible and no efforts are underway to develop technology that overcomes these limits.
F1	**F1.1**	Production is currently taking place.	
	F1.2	Capital funds have been committed and implementation of the development is underway.	These Sub-categories not defined in the Supplemental Groundwater Specifications, but individual operators may find them useful.
	F1.3	Studies have been completed to demonstrate the technical feasibility of development and operation. There shall be a reasonable expectation that all necessary approvals/contracts for the project to proceed to development will be forthcoming	
F2	**F2.1**	Project activities are ongoing to justify development in the foreseeable future.	
	F2.2	Project activities are on hold and/or where justification as a development may be subject to significant delay.	
	F2.3	There are no plans to develop or to acquire additional data at the current time due to limited potential.	

F Axis - Technical Feasibility and Maturity			
Category	*Definition*	*Supporting Explanation (UNFC (2019))*	*Additional Groundwater Context*
F3	**F3.1**	Site-specific studies have identified a potential development with sufficient confidence to warrant further testing.	
	F3.2	Local studies indicate the potential for development in a specific area but requires more data acquisition and/or evaluation to have sufficient confidence to warrant further testing.	
	F3.3	At the earliest stage of studies, where favourable conditions for the potential development in an area may be inferred from regional studies.	
F4	**F4.1**	The technology necessary is under active development, following successful pilot studies, but has yet to be demonstrated to be technically feasible for this project.	
	F4.2	The technology necessary is being researched, but no successful pilot studies have yet been completed.	
	F4.3	The technology is not currently under research or development.	

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

33. The UNFC G-Axis score is intended to convey the level of confidence in the estimate of quantities expected from a development project. Groundwater projects are assessed by their ability not only to deliver a particular total volume of groundwater, but to do so at a reliable rate of production and with an expected chemical quality. The Supplemental Groundwater Specifications use the G-Axis Category definitions and scores to capture confidence a project's deliverability as measured by these three aspects: total volume, yield or rate of production, and chemical quality.

34. Factors that influence an estimator'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 wells and monitoring wells on site
- Independent monitoring of changes to water, land, ecosystems, society through means like remote sensing
- Climatic stationarity or resilience in face of possible climate change
- The 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 a single, well-founded predictive hydrogeological explanation 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 complete 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.

35. The Supplemental Groundwater Specifications for the G Axis are as follows:

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 specific deterministic scenarios (low, best and high cases) or (ii) a probabilistic analysis from which three outcomes (P90, P50 and P10)[3] 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	The G1 Degree of Confidence represents the low case or P_{90} 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.		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_{50} value of a statistical distribution of possible values. It is recommended that the G1+G2 level of confidence be applied to groundwater projects. This is because it represents the most likely value of the quantities representing the 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. 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

G Axis – Degree of Confidence			
Category	*Definition*	*Supporting Explanation (UNFC (2019))*	*Additional Groundwater Context*
		with a project. Additional Comments: The G axis Categories are intended to reflect all significant uncertainties (e.g., source uncertainty, geologic uncertainty, facility efficiency uncertainty, etc.) impacting the estimate 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. Where P90 means that there is a 90 per cent probability that the actual outcome will equal or exceed this estimate. Similarly, P50 and P10 reflect 50 per cent and 10 per cent probability respectively that the actual outcome will equal or exceed the estimate.	data should be available for the test wells for the production wells. Other considerations for inclusion in a high quality, best-estimate of groundwater quantities include: • 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 or its location in its host groundwater flow-system • 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 possibilities that may lead to project failure and thereby improve the quality of the best estimate • 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, or based on machine learning. In all cases the predictions of the model will be reasonably matched by the field observations • There should be sufficient data for the parameter heterogeneity in the calibrated models to be geostatistically characterized • 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 this risk can probably be mitigated through design and operational considerations and not impact the best estimate.
G1+G2+ G3	Product quantity - high case.		The G1+G2+G3 Degree of Confidence represents the high case or P_{10} 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.
G4	Product quantity associated with a Prospective Project,	A Prospective Project is one where the existence of a developable product is based primarily on indirect evidence	A G4 level of confidence is applied when there is no direct information exists from a site on which to base an estimate of groundwater quantity or chemical quality for

G Axis – Degree of Confidence			
Category	*Definition*	*Supporting Explanation (UNFC (2019))*	*Additional Groundwater Context*
	estimated 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.	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. 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. 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: • Past records of extraction of favourable chemical quality, rates of production, or total quantity in the target formation or aquifer at a site inside the region of interest • Records of current extraction of favourable chemical quality, rates of production, or total quantity in the target formation or aquifer at a site outside the region of interest • 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 target range. When possible, the probability that this condition can be met should be assessed • 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.

G Axis – Degree of Confidence			
Category	*Definition*	*Supporting Explanation (UNFC (2019))*	*Additional Groundwater Context*
G1	No Sub-categories defined		These Sub-categories not defined in the Supplemental Groundwater Specification, but individual operators may find them useful.
G2	No Sub-categories defined		
G3	No Sub-categories defined		
G4	G4.1	Low estimate of the quantities.	
	G4.2	Incremental amount to G4.1 such that G4.1+G4.2 equates to a best estimate of the quantities	
	G4.3	Incremental amount to G4.1+G4.2 such that G4.1+G4.2+G4.3 equates to a high estimate of the quantities.	

B. Groundwater Project Classes

36. The UNFC E, F, and G-Axis Category scores 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 previously outlined.

C. Viable Groundwater Projects: E1/E1.1/E1.2-F1-G1+G2

37. 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.

38. 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 the event that natural circumstances, such as the depth of the source, de-emphasize application of general surface environmental conditions then the Sub-category of E1.1 applies.

39. In the event that social necessity for groundwater overcomes broader social, environmental, or economic considerations, a Sub-category of E1.2 applies. These are referred to as Socially Necessary Groundwater Projects to highlight their special considerations.

40. 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.

D. Potentially Viable Groundwater Projects: E2-F2-G1+G2

41. 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.

E. Prospective Groundwater Projects: E3-F3-G4

42. 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.

F. Non-Viable Groundwater Projects: E3-F2-G1+G2/G4

43. 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 becomes non-viable for some reason, but its existence needs to be tracked until its hydraulic impacts are gone from the source.

G. Groundwater Production that Will Not Be Used: E3.1-F1-G1+G2

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

VII. Supplemental Specifications for Groundwater Projects

A. Project Plan and Definition

45. A Project is a defined development or operation which provides the basis for environmental, social, economic and technical evaluation and decision-making (UNFC (2019)).

46. The project plan may be detailed or conceptual (in the case of long-term national resource planning). The project plan should be sufficiently detailed to allow an appropriate assessment for the stakeholder needs at the defined level of maturity.

B. Project classification

1. Classification of projects based on the level of maturity

47. UNFC (2019) Part IV Specification G applies.

2. Distinction between [E1 E2 E3]

48. UNFC (2019) Part IV Specification H applies.

3. Environmental-socio-economic assumptions

49. UNFC (2019) Part IV Specification K applies.

4. Distinction between potentially produced quantities and undeveloped quantities

50. UNFC (2019) Part IV Specification I applies.

C. Project reporting

1. Basis for the estimate

51. UNFC (2019) Part IV Specification E applies. For groundwater projects, all production should be considered in the basis for the estimate plus all volumes attributable to E Classes 1.2 and 3.1 unless they already have been explicitly accounted for in an external groundwater-resource inventory.

2. Effective date

52. UNFC (2019) Part IV Specification C applies. For groundwater projects, it may be appropriate to use a local standard hydrological year as the effective date for annual estimation and reporting.

3. Product

53. UNFC (2019) Part IV Specification D applies.

4. Reference point

54. UNFC (2019) Part IV Specification F applies. For groundwater projects, a totalizing flow meter at the well-site downstream of any dissolved gas separator is typical practice. Reference points downstream of any treatment trains with evaporative or other consumptive loss should account for these losses in the reported estimate.

5. Aggregation of quantities

55. UNFC (2019) Part IV Specification J applies.

56. 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: (i) Remaining products not developed from identified projects, and (ii) Remaining products not to be developed from prospective projects.

57. 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 resouce inventory framework in order to properly assign categories, especially on the E-axis.

58. Groundwater quantities are divisible into stocks and flows. Groundwater stocks represent the volume of groundwater stored in subsurface formations at an instant in time. Groundwater flows represent the transfer of water between different stocks as a function of time. Groundwater is always in motion so there is always flow. Stocks may appear constant, but this is usually an illusory aspect of a groundwater system being in equilibrium with its boundary conditions.

59. When groundwater projects are in hydraulic communication with surface water, the flow from a well can deplete both groundwater stocks and surface-water stocks. Induced flow from surface-water stocks in response to groundwater development can sustain development almost indefinitely and ultimately replenish depleted groundwater stocks, provided those stocks and flows are large enough. The degree of groundwater depletion in the source and

the degree of induced flow plus reduction of stocks of surface water will affect viability of groundwater projects. These linkages mean that groundwater stocks and flows beyond UNFC-focused quantities available for production need to be considered when evaluating the total groundwater available for development from a given project.

60. 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. SEEA-Water explicitly recognizes the differences between stocks and flows for integrated water management and provides a useful framework for holistic water accounting. For water quantities, the key components of SEEA-Water are the Physical Asset Accounts and the Physical Flow Accounts. These correspond to the stocks and flows of a water system.

61. SEEA-Water breaks down the Physical Asset Accounts into the surface and subsurface entries that hold stocks of water. In UNFC (2019) terms, these entries represent the sources for Total Products plus stocks that cannot be associated with identified or prospective development projects now or in the foreseeable future. SEEA-Water breaks down the Physical Flow Accounts into the type of industry entities producing or using water. In UNFC (2019) terms, these entries represent the Products Produced. It also provides entries for transfers between stocks that are not produced but represent either natural flow of water and groundwater between stocks or flow between stocks induced from production but not produced.

62. In terms of the application of UNFC for groundwater quantities in a SEEA-Water or similar framework, the following recommended assignments should be made for reporting of groundwater quantities:

63. *Viable Groundwater Projects* quantities produced from E-categories E1 and E1.1 should be assigned as Water Sold or used in production. In the SEEA-Water framework, these quantities would be entries into the Physical Flow Accounts for a given reporting period by industry.

64. Quantities of water produced by projects of the class *Groundwater Production from a Non-Groundwater Project* E3.1 should be assigned to Water which is unused or consumed in operations. In the SEEA-Water framework, these quantities would be entries into the Physical Flow Accounts for a given reporting period by industry and probably generate a corresponding entry for disposal or return flows to the environment in the Physical Flow Accounts.

65. Quantities of groundwater induced to move between groundwater stocks or between surface water stocks and groundwater stocks from a viable development should be recognized in the SEEA-Water Physical Flow Accounts even though they are not captured as part of a UNFC Class.

66. Estimates of quantities of water produced by Socially Necessary Groundwater Projects E1.2 for the groundwater management unit, etc. should be entered into the Physical Flow Accounts. There is a place for domestic water-well production for example. Quantities of groundwater induced to move between groundwater stocks or between surface water stocks and groundwater stocks from the category of Socially Necessary Groundwater Project Class should be recognized separately in the SEEA-Water Physical Flow Accounts. These quantities are going to be poorly known and may only be estimated as those volumes required to reconcile stocks and flows.

67. Total Products not yet produced from *Viable Groundwater Projects* and *Potentially Viable Groundwater Projects* should be tracked as entries in the SEEA-Water Physical Asset Accounts, as they remain part of the natural stock until produced. It is common in other resource systems to use the word "reserves" to designate quantities yet to be produced from UNFC-style *Viable Projects* or likely to be produced from *Potentially Viable Projects* in the foreseeable future. These terms are used in some national groundwater-management systems. There should be no contradiction in using the term "reserves" for Products not yet produced from these Classes of projects in these systems, but it is not a feature of these Supplemental Groundwater Specifications. If the term "reserves" is used, then these stocks should also be

recognized in the SEEA-Water Physical Asset Tables as a type of claim on the stocks for future production to avoid double allocation.

68. The total groundwater stock in a groundwater source, net of reserves or claims by *Viable Projects* and *Groundwater Production for Non-Groundwater Projects*, may be assigned to UNFC *Prospective Groundwater Projects* and *Non-Viable Groundwater Projects*, or tracked as stocks not available for development. This decision is somewhat arbitrary and needs to be informed by regulatory or policy frameworks in the jurisdiction of the project. These quantities should be entered in the SEEA-Water Physical Asset Accounts or equivalent. The basis of this decision should be documented.

69. 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.

70. 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.

6. Use of Numerical Codes

71. UNFC (2019) Part IV Specification A applies.

7. Units and Conversion Factors

72. UNFC (2019) Part IV Specification M applies. SI units are recommended over field units or other units of measure such as standard English and US units of measurements. Where the latter are employed, it is recommended practice to report SI values first along with conversion factors for the other system of units.

8. Documentation

73. UNFC (2019) Part IV Specification N applies.

D. Quality assurance and quality control

1. Evaluator qualifications

74. UNFC (2019) Part IV Specification L applies.

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