System Subsystem Specification

for the

KNEAD Example System

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DOCUMENT CHANGE HISTORY

The following table is a simple list of released revisions sent for review. Records of reviews and the review artifacts are saved with reviewer information in the The KNEAD Projectartifact repository.

Change Record

Date	Version	Author(s)	Change Reference
23 Feb 2024	P1	Lewis Collier	Preliminary DRAFT version
11 Apr 2024	P1	Zachary Steinberg	DRAFT version
06 May 2024	v1.0	Zachary Steinberg	Final version

Each subsequent "section" outlines changes in each release.

Items in this version that are marked with change bars have been modified from the most recent previous version (e.g. P3 changes from P2) or are new as of the current revision.

Draft P1 Preliminary version of this document.

Draft v0.1 Draft Version for Design Assignment 2.

Final Version v1.0 Final Version for final Project.

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CHAPTER 1

Scope

This document provides the System / Subsystem Specification (SSS) for the Garden Control System. The system will be referred to as the GCS.

1.1 Identification

The Garden Control System described in this document shall be known as GCS version 1. However, the SSS described herein shall be applicable to pre-releases such as Beta-releases for a phased release as listed for each requirement. The major system interfaces and capabilities are fully specified in Chapter 3.

1.2 System Overview

The Garden Control System will be able to measure moisture levels and control irrigation in raised garden beds. The purpose for GCS is to maintain ideal gardening and growth conditions for fruits, vegetables, and other garden plants throughout a growing season. The goal for GCS is to automate the watering process for DIY gardeners. GCS will monitor temperature, moisture levels, and additionaly environmental factors to determine when to water the plants. Garden Control System is being developed by Zachary Steinberg and sponsored by University of Maryland Graduate Engineering. The operator and maintaner of GCS will also be Zachary Steinberg. The GCS will be operated outside along raised garden beds. GCS is designed to be used by home gardeners. It is not intended for industry. GCS will be controlled by a Raspberry Pi Pico W microcontroller board.

Figure 1 shows the development kit used for the GCS system. This diagram shows the major external interfaces that provide the capabilities of GCS. As are shown, the GCS can monitor and maintain a garden system through it's environmental sesnors and control of a water pump.

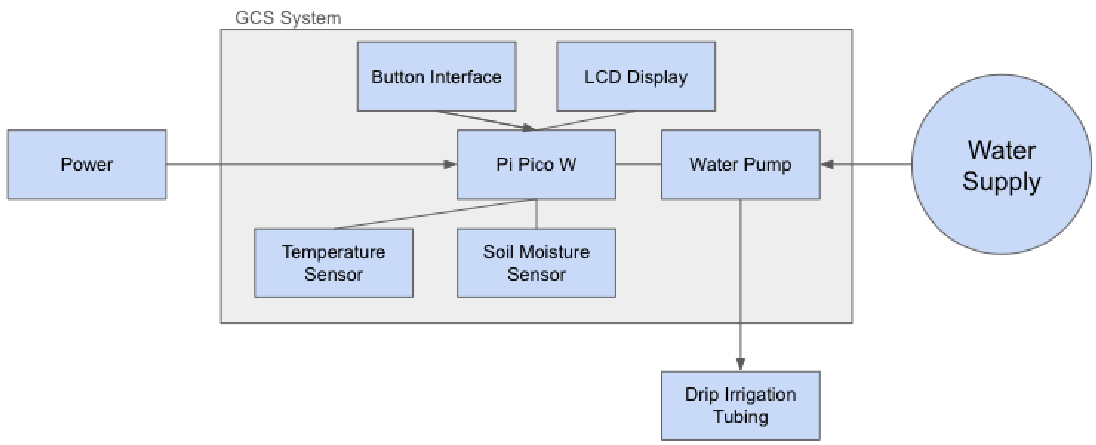

Figure 1: System Overview for the Garden Control System

1.3 Document Overview

This section provides information about this document's security/privacy considerations, contents, structure, and version information. This section also provides information regarding how specifications are formatted in this artifact and how they can best be understood.

1.3.1 Security and Privacy Considerations

This document is not subject to CUI restrictions.

This section provides information about the format of this document. Some information provides general details about the format of this specification document. This information, such as formatting details, is common across all levels of specification documents. Other information is specific to this particular document. This information is provided to assist the reader in understanding the format and layout of the information contained in this document.

1.3.2 Document Sections

This document format is based upon the guidance in the SRD template from MIL-HDBK-520A [1]. The specifications and associated acceptance criteria are documented following the guidelines of ISO-12207 [2] and MIL-STD-498 [3] (from which ISO-12207 originated). The document follows the SSS DID [4], with a few minor tailoring changes.

The first format tailoring change allows for the system interfaces to be specified before the system capabilities. This follows standard structured design practice (e.g. Yourdon's Structured Method) whereby the system context is provided before the design itself. The net result of this change is that system capabilities are presented in section 3.3 instead of 3.2, as prescribed in the SSS template, and external system interfaces are described in section 3.2 instead of section 3.3 as prescribed in the SSS template. This allows the data inputs to the system to be defined *before* they are used in the capabilities section.

The second format tailoring change relates to placement of general material within the document. The qualification provisions and traceability details, if applicable, are listed with each requirement. This formatting, which is allowed in the SSS DID [4], allows the reader to view all relevant information for each requirement in a single location, rather than requiring constant page turning. This information may be duplicated in Sections 4 and 5, respectively, but if done this way, it can be generated automatically to prevent manual duplication errors. The table of acronyms is also listed in chapter two, versus the notes section, so that it may be parsed by readers before encountering most of the acronyms.

Otherwise, this document follows the listed SSS sub-section order.

Section 1 provides an overview of the system and this document.

Section 2 lists general and application-specific reference documents as well as glossary terms and acronyms.

Section 3 details the specifications for the system.

Section 4 maps the specifications to quality provisions.

Section 5 traces specifications to the original source.

Section 6 if needed, lists any general notes as may be applicable beyond any notes provided in the requirement and expectation tables in section 3.

Appendices if needed, provide additional information as may be needed.

1.3.3 Document Version Information

This document was produced in LaTeX and *BibLaTeX/Biber*. The editing and document preparation were performed using MiKTeX version 2.9 with the build option [LaTeX ⇒ PS ⇒ PDF]. The LaTeX*svn-multi* package was used to glean SVN tracking information, when files are stored in an "SVN" version control system. The style `KNEADdocument` was used to provide the LaTeX and *BibLaTeX/Biber* formatting details.

1.3.4 Specification Formatting

The specifications are listed and numbered by document sections. The fully qualified specification numbers include the sub-section in which it is contained. These specification numbers are tied to the document level thus they are numbered from 1 to N for each sub-section of the requirements section. This is done to allow for additions within a sub-system without affecting the numbering in other sub-systems. Once a specification has been added, it cannot be deleted, only its status may be changed to "inactive" or "deleted" to preserve numbering.

This document allows for marking changes to specifications. All specifications may be marked with a change bar. This generally implies that one or more parts of a specification changed from the prior revision. A note should be provided to indicate the reason for the change, and when, so that future versions of the document, which do not include the change bar, still have rationale included for the current value.

The system specifications are listed in a common table format as shown in Requirement 1.3.1.

Specification 1.3.1 Specification Table Format	
Text	1. The first row of a table provides a unique number and a title for the requirement or expectation. This row is generated from the first 3 arguments. 2. The second row of the table provides the specification text of the requirement. Normally this is a single sentence with a single testable requirement (shall) statement. This example uses an enumerated list in order to describe all the rows in a single table. 3. The next row of the table provides the status for the specification listed in the table. This includes the applicable phases or release versions in which the required feature is supported, where S $\in$ {(T)hreshold, (O)bjective, (I)nactive, (D)eleted}. 4. The next row of the table provides the acceptance criteria. This row follows the form of "This requirement shall be verified by V $\in$ {inspection, demonstration, test, analysis}." Additional information regarding testing can be provided in the notes section. 5. The next row of the table provides the traceability of the requirement. The traceability connects the requirement to a higher level document that calls out the need for a requirement. The structure of traceability is expected to be of the form "This requirement traces to MIL-STD-498 [3] and ISO-12207 [2]." Note that the source is expected to be listed in the reference documents section. 6. The final row of the table provides, if applicable, notes for the specification. Notes are not a formal part of the requirement or expectation but provide supporting information regarding the feature.
Status	**All phases** This format is active for all specifications in this document.
Acceptance	This specification is not a testable requirement for the system; it is for demonstration purposes only.
Traceability	**N/A** There is no traceability for this requirement.

P1

The status designations for each specification S $\in$ {(T)hreshold, (O)bjective, (I)nactive, (D)eleted} are based on the following criteria.

`(T)` **- Threshold** Items marked "`(T)` - Threshold" are driven by the project threshold needs that must be met in the specified phase.

`(O)` **- Objective** Items marked "`(O)` - Objective" are objective goals of the system in the specified phase. These requirements may stay (O) for all listed phases or may transition from (O) to (T) in future phases. This provides hints as to future expansion of system capabilities so the design can account for the feature without significant later rework.

`(I)` **- Inactive** Items marked "`(I)` - Inactive" are requirements that are not currently to be met by the system in the specified phase. Unlike '`(O)` - Objective" requirements, (I) requirements may be in limbo in terms of certain details but their inclusion may also provide hints as to future expansion of system capabilities.

(D) - **Deleted** Requirements that are not to be met by the system are marked by "(D) - Deleted". Use of this status, vice removal of the requirement text, preserves the numbering of subsequent requirements and notes that the requirement once was invoked. The rationale for the deletion should be included in the notes section.

External tools have been written that allow for automatic generation of other documentation. Specially, data for chapters and appendices that follow the requirement specifications, can be gleaned automatically to ensure integrity between the sections of the documents. In addition, the listing of KPP and KSA values into a "B-spec" can be automated. Finally, the full set of requirements, and the associated attributes, are exported to a comprehensive .CSV file for import into external tools such as DOORS™.

This table approach offers other advantages besides automated parsing for import into tools. As can be seen in Table 1.3.1, and in all the specifications, this format groups all information for each specification into a separable and easily viewed structure. The document sections and subsections provide a logical grouping of the specifications but the table allows all pertinent information to be grouped, vice being split across major sections of the document. This grouping allows for easier presentation since each grouping is similar to a "PowerPoint" presentation slide. And, as will be seen in Section 1.3.5, it can help the writer organize specifications. The approach also allows for a "List of Specifications" to be generated. Each table is listed in the list of specifications so that each high level grouping can be quickly located from the list. Of course, the tables are located in the appropriate sections as noted in Section 1.3.2 so they can be found in that manner as well.

Another major advantage of the table format is the "Notes" section. As specifications are developed, there will be many issues to be resolved. And, once issues are clarified, tracking the rationale for the decision is just as important as recording the answer [5]. Thus the notes section helps the reader and the writer. The writer has a logically grouped place to put notes for each specification and the reader can easily find them without having to refer to footnotes, separated sections, or external documentation.

1.3.5 How To Read Specifications

System Performance Specification (SPS) documents, by their very nature, are a collection of independent but interconnected facts. Systems require interfaces from which inputs are consumed and to which outputs are produced. These input data are transformed by the capabilities to produce the outputs. The entire system has myriad other requirements ranging from data formatting through physical limits on things like the enclosure and packaging.

Finally, at the system level, specifications need to dictate *what, and, how well* a system must perform. Likewise, in order to separate documentation functionality, the SPS should not state explicitly *how* the system is to be formed, except in very special circumstances. Given the disparate nature of the requirements, system performance specifications can be hard to digest.

System / sub-system Segmentation Specification (SSS) and Software Requirements Specification (SRS) documents suffer from many of the same issues as do SPS documents. An SSS turns the performance specification into a first level design. Where the SPS has disparate performance requirements, the SSS has disjoint hardware and software configuration items listed as well as a mapping of the two items on to, and in to, each other. For the requirement management function, each element of the system design in the SSS traces back to the overall SPS specifications. Only at the SRS level do the requirements start to focus on a single item. Thus, the SSS and SRS level documents describe share a common contextual issue with the SPS document.

An understanding of the documents' structures is needed to help parse the information. The developers of MIL-STD-498 [3], however, understood this and devised a format that can help manage the information overload. The method by which this is accomplished is to organize requirements into eighteen specific groupings. By understanding these groupings, a reader can improve their understanding of the system described by the requirements by understanding that specific information is listed in specified sections.

These documents follow a *read-forward* mentality so that base information is provided before it is actually needed.[1] For example, the referenced documents (and in this document the list of acronyms and glossary terms) are provided in the second chapter, before most items are actually cited. By presenting this information to the reader before citation, the format allows the reader to glean upfront information about the kind of things that will be covered later on in the document. Presentation of the referenced material ahead of the document body also allows the reader to have a priori information before encountering the symbol in the text. By understanding these formatting clues, the reader is able to be prepared for what is coming further down the road in the document.

Another reason for this organization is that different readers process information differently. There is no one format that will be best for all readers. By having the information

[1] In fact, the read-forward philosophy extends across the documents as well but that topic is beyond the scope of this discussion.

in standardized sections across all such performance specifications, however, readers can use the document as a reference as needed. As an example, Section 3.1 of these documents will always define the system states and modes. If a reader wants to look up this information, it is always in that section. And, since it is listed first, all ensuing sections can reference states and modes in order to qualify their requirements. Likewise, having external interfaces presented *before* the capabilities means that the capabilities can define the transformations without having to worry about how the data is ingested into the system; the data is already “in the system” from a reader’s point of view when the data is needed to define the transformation.

This separation between, and the presentation order of, the data and processing is important when the same data supports multiple capabilities. A hierarchical description of “derived” requirements often would have a capability definition leading to the requirements for the data needed by the capability. In the case, which occurs often, where the data is used in two different transformation capabilities, a hierarchical approach of capability leading to external interfaces is met with the problem of which capability gets to have the data interface in its tree. This approach also leads to the dilemma of what to do when that first capability is no longer needed by the system but the second capability, and thus the data defined under the first capability tree, still *is* needed by the system. Just as loosely coupled software is more maintainable, so are loosely coupled requirements.

A final note about reading actually comes from ideas about how to write a requirement document. The document format dictates a linear flow from start to finish. A reader often reads a document the first time from front to back; this is why the *read-forward* approach works.

The writer, however, is *not* constrained in the same linear manner. Thus, while writing requirements about a capability, the idea for a new state or mode may arise. The writer can easily jump to the states and modes section in order to add in the information and then return to complete the capability that led to the new state or mode, safe in his knowledge that when the reader sees this new specification, they should have already seen the newly defined state or mode that is used to qualify the requirement since the state or mode was already presented in an earlier section.

Readers can use this information to enjoy the fact that the writer jumped around in the writing phase to save the reader the same effort when trying to read the document. By understanding the sections and the expected contents of the sections, which are defined in the SSS DID [4] and the related MIL-STD-498 [3] document templates, a reader can read cover-to-cover, or jump to the needed information quickly, knowing that the writer put the information in the specified sections to make finding the information easier for the reader.

1.3.6 Specification Traceability

A project typically has several levels of statements of what needs to be done. Often an Operational Concept Description (OCD) is developed to provide a high level description of the system to be developed and its expected uses. A set of documents that follows the MIL-STD-498 [3] DID formats is often developed for a project. A Statement of Work (SOW) or a Statement of Objectives (SOO) is often developed to direct contractors on a project. While a SOW or SOO is supposed to be more contractual statements of tasks and objectives rather than actually trying to specify what needs to be built, these documents often, however, do include system requirements. A better method is to have the SOW or SOO reference a formal SPS so that the full scope of the system can be defined. Situations for every project differ so the main thing to understand is that there will be many documents and that their contents need to be related to each other.

Given the number of specifications for a system, and all the levels at which the specifications may be written, understanding if all needs of a system are being met is critical. Different documents have different levels of specifications and design materials. A mapping between the specifications at all of the different levels is essential to make sure that the design meets all of the stated needs of the system and that the system does not include capabilities that are not required.

As a system performance specification, the SPS is the highest level of specification of systems requirements. This document defines *what* the system needs to do without saying *how*. Thus, in general, there should be nothing higher to which the requirements in a SPS can be traced. In practice, however, some document such as an OCD for the system, informal customer requirements documents, or a SOW or SOO for the project may be provided that indicates some of the system needs. If the specifications in the SPS meet all the use cases in the OCD then the system meets the needs but only if the use cases are all inclusive. Likewise, if the SOW or SOO tries to list things the system needs to do, these needs must be tracked. And, of course, statements of need in any straw-man requirements documents need to be met. Once the fully developed SPS specifications are captured then the higher level document(s) be examined to make sure that, at a minimum, all of those things listed are captured in the SPS. This process ensures that the SPS is compliant with the other "defining" stakeholder documents.

To ensure coverage compliance, each of the higher level needs, whether implied or explicitly stated, needs to be mapped to the SPS specification(s) that cover each given need. This is expected to result in a one-to-many relationship where many of the SPS specifications are mapped to a single upper level need. And, each specification in the SPS can be mapped to multiple needs depending on the independence of the needs. The details of how to do this mapping, which is best handled through some relational database tool (e.g. DOORS™), are beyond the scope of this introduction. The important thing to note is that this traceability determines if the SPS covers the known needs of the system. Since a well-formed SPS includes many more facets than an OCD or SOW/ SOO, there may be orphan SPS requirements that do not map directly to the higher level documents. However, there can be no orphan needs from the stakeholder documents that do not map to the SPS. The key here is to perform a mapping between the SPS and any higher level stakeholder documents to ensure that the specifications of the SPS provide compliance to the higher document(s).

Another way of saying this is to summarize the overall design philosophy as follows: a level of design should be carried out and mapped to higher level artifacts rather than simply "deriving" requirements from the higher level documents. This mapping process, thus, is *not* a way to derive a fully defining set of requirements for the SPS. The act of "deriving" specifications of system from a non-specification document such as a OCD, SOW, or SOO does *not* ensure that all the true system needs are captured. In fact if this approach is followed then often many requirements are missed because of the incomplete nature of the OCD, SOW, or SOO list of system needs.

An SPS, just like any level document, needs to be developed using domain knowledge and by following best practices and a well-defined documentation format. All of the things that must be considered for defining a successful system need to be included in the SPS. Note that, obviously, if the SOW did all of this then the SOW would be the SPS. But, in practice, this rarely ever happens, nor should it. The SOW or SOO are programmatic level documents that list things to do to build the system; they are not supposed to define the system. This is the job of the SPS.

The system / sub-system segmentation specification (SSS) is the second level of specification of systems requirements. The SSS starts to define *how* the system will meet the needs and should include a top-level system decomposition (or segmentation) of capabilities from the SPS to the sub-systems of the system. In a typical documentation set, there should be a higher-level document (i.e. the SPS) to which the specifications in the SSS can be traced. The goal here is to ensure compliance with the higher level document much as was done with the SPS and higher level programmatic documents. If the design specifications in the SSS cover all the performance specifications in the SPS then the system design covers the documented system needs. This does not mean that the system *will* meet the performance specifications, it just means that there are no obvious holes. And, of course, if some SPS specifications are not covered in the SSS then those specifications obviously cannot be met by the system design.

Since the SPS and SSS documents are all explicit statements of requirements, there can be no gaps between the specifications in them. If there is no mapping from at least one SSS requirement to each of the SPS requirements then the system cannot meet the stated requirements of the SPS. While the goal here is to ensure that the specifications of the SSS provide coverage to the higher document, true compliance can only be determined through design analysis and testing efforts. And, if there is an orphan SSS requirement then the questions must be asked: "Why is this requirement included?" and "Can this requirement be deleted?". Taken together, the SPS and SSS documents can form the basis for a well-formed design artifact set: References to higher-level artifacts document where the system goals came from and the code (and hardware) level artifacts (source code and CAD models) should describe the final product details. Coupled with appropriate test documents, this level of design process and documentation generation should adequately allow for successful development while preserving the architectural aspects for future revisions and modifications.

Because this is the overall system performance specification, this document may provide traceability to miscellaneous project documents. This allows for tracking of related doctrine, vendor, and draft specification requirements as the document is being created.

CHAPTER 2

References

This section provides a list of referenced items for this document.

2.1 Acronyms and Abbreviations

This section defines acronyms and abbreviations used in this and related documents.

Table 1: Acronym Definitions

Acronym	Definition
GCS	Garden Control System
UMD	University of Maryland
MAGE	Maryland Applied Graduate Engineering
ENPM	Engineering Professional Masters
End of acronym definition table	

2.2 Glossary and Definitions

This section defines glossary terms used in this and related documents.

Table 2: Glossary Terms and Definitions

Glossary Term	Definition
Communications	Communication is information transfer, among users or processes, according to agreed conventions.
Customer	The local government project lead who is acting as a general manager for the sponsor to ensure that the contractor team executes the project according to stakeholder goals.
Raised Garden Bed	Raised-bed gardening is a form of gardening in which the soil is raised above ground level and usually enclosed in some way.
Drip Irrigation	Drip irrigation is a method of watering plants by slowly dripping water through pipes with holes into the soil, either buried or slightly above ground.
End of glossary terms table	

2.3 Referenced Documents

This section lists the referenced documents for this document. The references are categorized into two categories:

External Documents not directly associated with this project.

Project Documents that are directly associated with this project.

2.3.1 External Documents

[1] US Department of Defense. *Department of Defense Handbook – System Requirements Document Guidance*. Mar. 2010.

[2] IEEE and EIA. *Software life cycle processes*. Mar. 1998.

[3] MIL-STD-498. *Military Standard Software Development and Documentation*. Dec. 31, 1994.

[4] DI-IPSC-81431. *Data Item Description for System Segmentation Specification (SSS)*. Dec. 31, 1994.

[5] Frederick P. Brooks. *The Mythical Man-Month: Essays on Software Engineering, 20th Anniversary Edition*. Addison-Wesley Professional, Aug. 1995. ISBN: 0201835959.

2.3.2 Project Specific Documents

[6] The KNEAD Project. *System Performance Specification for the KNEAD Example Project*. Dec. 31, 2023.

[7] The KNEAD Project. *System Subsystem Specification for the KNEAD Example Project*. Dec. 31, 2023.

CHAPTER 3

Requirements

This section provides the requirements that drive the design and implementation of the GCS. These specifications are divided into the major segments of the system. Each requirement is listed in the segment that provides the specified capability, thus this section provides an immediate mapping of implementation requirements to the segment in which each requirement is met. Each requirement also includes traceability to high-level requirements that drive the specific capability. Validation methodology is provided here but verification traceability is provided in the STS artifacts.

The requirements also are specified in an order that generally allows for all precursor requirements to be stated before they are needed by a successor requirement. Thus, States and Modes are defined at the onset so that they can be used to regulate when external interfaces and processing steps may occur. Likewise, external interfaces are described so that the data from the interfaces may be used in, or created by, the ensuing processing. Once the processing is specified, the internal interface and data requirements are listed, showing how the overall system segments tie together. The remainder of the sections follow a somewhat similar pattern, but these latter sections contain disparate requirements that are separated and organized in a standard way so the contents can be easily scanned to locate specific requirements based on their type and expected location within the SSS.

These specifications also include qualifications for both Threshold (must meet) and Objective (want to meet) requirements for GCS. The reader is cautioned to ensure that the requirement details be understood for the two modifiers.

3.1 States and Modes

This section lists the states, sub-states, modes, and sub-modes that are provided by the system. While these terms can be construed in many ways, for this document, the following meanings are used:

States are the basic configurations of the system.

Sub-states are the effective state of being for the system.

Modes are the basic functions to be performed by the system when in a given state and/or sub-state.

Sub-modes if listed, are specific function modifications to be performed by the system within the given mode/function.

3.1.1 States

A summary of the states is provided in Table 3. See the formal specifications, if applicable, in the following sections for formal statement of the state requirements, and accompanying notes that provide further clarification on the meanings of the states.

STATES	
State Name	**Garden Control System States**
Irrigation On	The GCS irrigation system is active.
Irrigation Off	The GCS irrigation system is off.

Table 3: Summary of States for Garden Control System

Specification 3.1.1.1 Irrigation On	
Text	Irrigation On
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by demonstration that the Garden Control System activates the irrigation system.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. The irrigation system is able to turn on. The system will control a drip irrigation system.

Specification 3.1.1.2 Irrigation Off	
Text	The GCS irrigation system is deactivated.
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by demonstration that the GCS irrigation system is deactivated.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. N/A

3.1.2 Modes

A summary of the modes is provided in Table 4. This table also provides a list of the states in which each mode is valid. See the formal specifications, if applicable, in the following sections for formal statement of the mode requirements, and accompanying notes that provide further clarification on the meanings of the states.

MODES		
Name	**Summary**	**Valid States**
Active Monitoring	The GCS shall actively monitor environmental data to determine if and when the irrigation system needs to activate.	Irrigation On Irrigation Off
Scheduled	The GCS irrigation system will be on a set schedule and regularly activate after a certain time has passed.	Irrigation On Irrigation Off
Manual Activation	The GCS irrigation system is manually activated.	Irrigation On Irrigation Off

Table 4: Summary of Modes for Garden Control System

Specification 3.1.2.1 Active Monitoring	
Text	The Garden Control System shall actively monitor environmental data to determine if and when the irrigation system needs to activate.
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by demonstration.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. The Active Monitoring state describes the capability to actively monitoring environmental data and decided whether or not to activate the GCS irrigation system.

Specification 3.1.2.2 Scheduled	
Text	The Garden Control System irrigation system will be activated and run on a set schedule.
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by demonstration.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. The irrigation system will be able to run via a schedule. In the Scheduled mode, GCS will activate the irrigation system for a set time and duration.

Specification 3.1.2.3 Manual Activation	
Text	The Garden Control System irrigation system shall be manually activated.
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by demonstration.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. The manual activation state disregards environmental data measured by the GCS sensors. The irrigation system will be activated for a set time period or can be manually turned off.

3.1.3 Sub-Modes

A summary of the sub-modes is provided in Table 5. This table also provides a list of the mode in which each sub-mode is valid. See the formal specifications, if applicable, in the following sections for formal statement of the sub-mode requirements, and accompanying notes that provide further clarification on the meanings of the states.

SUB-MODES		
Name	**Summary**	**Valid Sub-States**
Temperature Monitoring	GCS will monitor temperature and activate the irrigation system based on a temperature threshold	Active Monitoring
Soil Moisture Level Monitoring	GCS will monitor soil moisture and activate the irrigation system based on a moisture threshold	Active Monitoring

Table 5: Summary of Sub-Modes for Garden Control System

Specification 3.1.3.1 Temperature Monitoring	
Text	The system shall monitor environmental temperature and activate the irrigation system for a set duration if the temperature is above a set temperature threshold.
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by demonstration.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. The Temperature Monitoring submode generalizes the case where the system is actively monitoring temperature. 2. When temperature crosses a set threshold, the irrigation system will activate for a set duration. 3. After the set time duration has passed, the irrigation system will deactivate.

Specification 3.1.3.2 Soil Moisture Level Monitoring	
Text	The system shall monitor soil moisture levels and activate the irrigation system when moisture levels drop below a certain threshold.
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by demonstration.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. The Soil Moisture Level Monitoring submode generalizes the case where the system is actively monitoring soil moisture levels. 2. When soil moisture levels drop below a certain threshold, the irrigation system will activate until soil moisture levels are above a certain threshold. 3. After soil moisture levels are above a certain threshold, the irrigation system will be deactivated.

3.2 External Interfaces

The external interfaces for this system are shown in Figure 2. The requirements for these interfaces are described in more detail in the following sections.

User The operator(s) that control the GCS, § 3.2.1

Network The network(s) that connect to the GCS, § 3.2.2

Power The network(s) that connect to the GCS, § 3.2.2

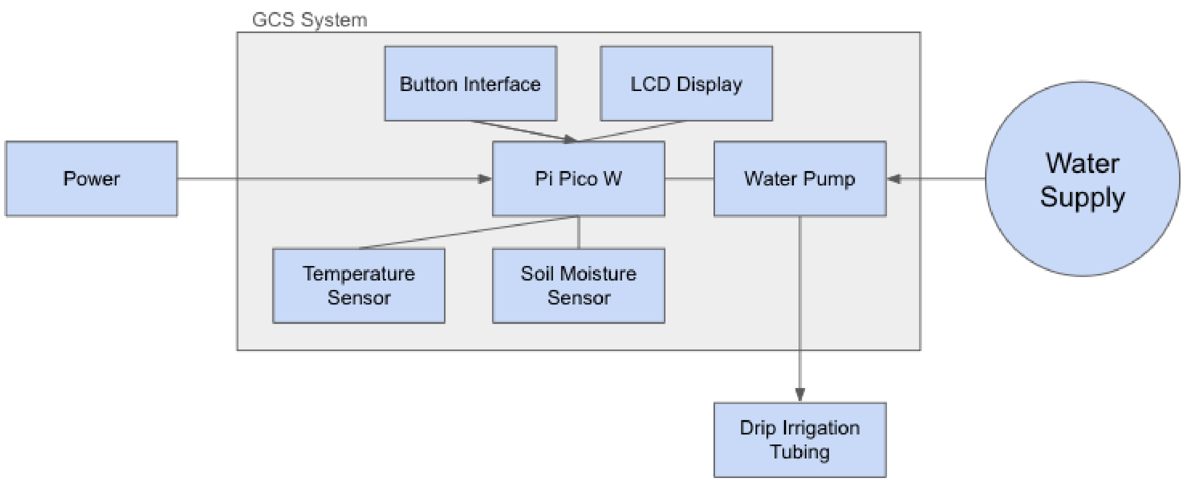

Figure 2: System Context Diagram (DFD-C)

3.2.1 Operator Interfaces

Specification 3.2.1.1 Rain Bird Drip Irrigation Tubing	
Text	All GCS variants shall be capable of connecting to a drip irrigation system made from Rain Bird Tubing.
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by demonstration.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. The irrigation system will be connected to the Garden Control System. 2. The irrigation system will be controlled by a water pump. 3. Product Page

Specification 3.2.1.2 US Solar Pump B3A 5V PWM Circulating Pump	
Text	All GCS variants shall be capable of connecting to a US Solar Pump B3A 5V PWM Circulating Pump that is capable of pumping water to drip irrigation tubing.
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by demonstration.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. The water pump will be controlled by the Garden Control System. 2. The pump must be a 5V pump 3. The water pump must be connected to a water source (i.e. hose or water tank) 4. Product Page

Specification 3.2.1.3 Water Supply	
Text	All GCS variants shall be capable of connecting to a water supply.
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by demonstration.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. The water supply can be a water tank or hose. 2. The water supply will feed into the water pump.

Specification 3.2.1.4 BME280 Temperature Sensor	
Text	All GCS variants shall be capable of connecting to a BME280 temperature sensor and interpreting sensor data.
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by demonstration.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. The temperature sensor will measure air temperature. 2. Datasheet 3. BME280 Driver

Specification 3.2.1.5 I2C Capacitive Moisture Sensor	
Text	All GCS variants shall be capable of connecting to a I2C Capacitive Moisture Sensor and interpreting sensor data.
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by demonstration.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. The I2C Capacitive Moisture Sensor measures soil moisture with a capacitive measurement. 2. Datasheet

Specification 3.2.1.6 GPIO Push Button Interface	
Text	All GCS variants shall be capable of connecting a button to a GPIO pin.
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by demonstration.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. A Button interface will allow Garden Control System users to activate manual and scheduled modes. 2. Each push button will represent a different watering mode. 3. Raspberry Pi Pico Button Guide

Specification 3.2.1.7 Adafruit Standard HD44780 LCD	
Text	All GCS variants shall be capable of connecting to a Adafruit Standard HD44780 LCD and displaying which mode GCS is set to.
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by demonstration.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. A LCD display will visualize what modes GCS is set to. 2. Datasheet

3.2.2 Network Interfaces

There are currently no network requirements for Garden Control System.

3.2.3 Power Interfaces

Specification 3.2.3.1 Power	
Text	All GCS variants shall be capable of connecting to ...TBD... Power.
Status	**Phase 1** Threshold
Acceptance	This requirement shall be verified by demonstration.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. N/A

3.3 Capabilities

This section defines the capability areas for the GCS. The segment design is structured to meet the requirements as specified in the SPS The KNEAD Project, *System Performance Specification for the KNEAD Example Project* [6] and SSS The KNEAD Project, *System Subsystem Specification for the KNEAD Example Project* [7] artifacts. Each area provides a subset of the overall capabilities for the GCS segments. These segments are shown in Figure 3, are summarized below, and are more fully specified in the following subsections.

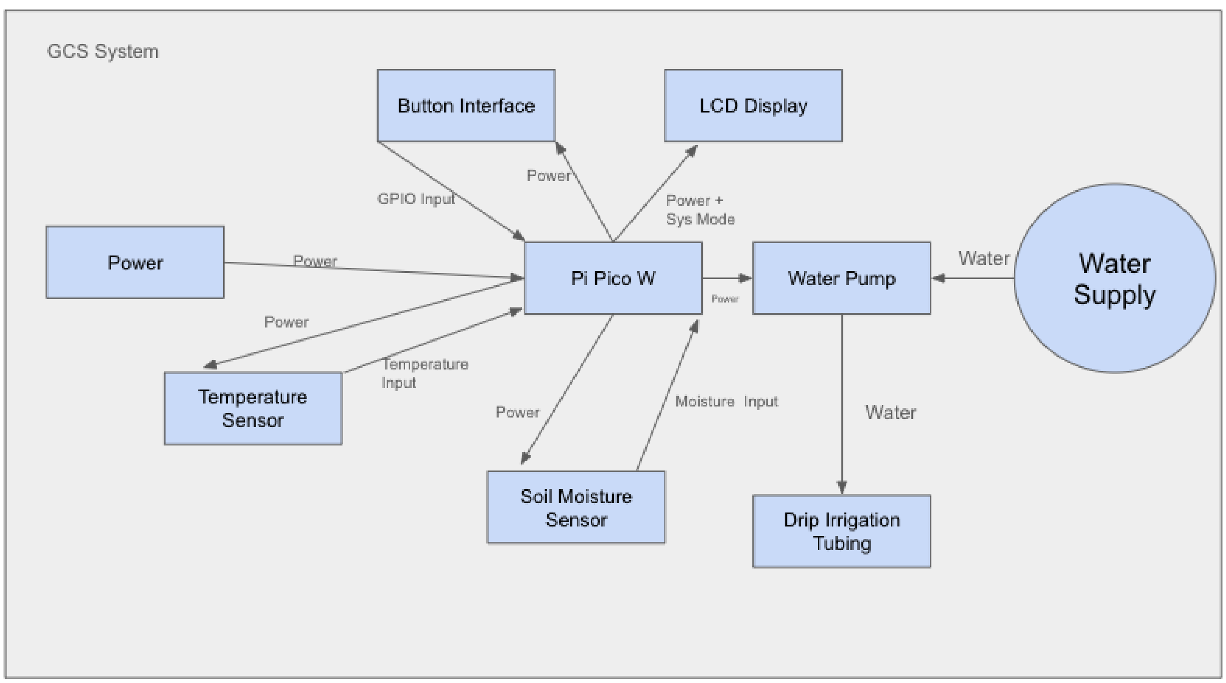

Figure 3: System Top-Level Diagram (DFD-0)

The capability requirements for these segments are described in more detail in the following sections:

Operator Processing handles the HMI interface to the operator and provides overall control and configuration to the GCS, § 3.3.1.

Network Processing handles the network interface, § 3.3.2.

Power Processing handles the power input and conversions as necessary, § 3.3.3.

Control Processing handles all major capability control, § 3.3.4.

3.3.1 Operator Processing

The operator requirements for Garden Control System are listed below.

Specification 3.3.1.1 Garden Drip Irrigation	
Text	All GCS variants shall be capable of proper garden drip irrigation until environmental thresholds are met or a set time duration has passed. The drip irrigation system will be made up of Rain Bird Drip Irrigation Tubing.
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by demonstration.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. The irrigation system will be capable of watering a garden of a set size. 2. Rain Bird Tubing

Specification 3.3.1.2 Water Pump	
Text	All GCS variants shall be capable activating and deactivating a US Solar Pump B3A 5V PWM Circulating water pump. The water pump will send water to a drip irrigation system and will be capable of running for 24-hours.
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by demonstration.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. The water pump will control water flow to an irrigation system. 2. US Solar Pump B3A 5V PWM Circulating Water Pump Product Page

Specification 3.3.1.3 Temperature Measurements	
Text	All GCS variants shall be capable of measuring temperature through the BME280 Temperature Sensor.
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by demonstration.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. Temperature will be measured via the GCS temperature sensor.

Specification 3.3.1.4 Soil Moisture Measurements	
Text	All GCS variants shall be capable of measuring soil moisture levels through the I2C Capacitive Moisture Sensor.
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by demonstration.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. Soil moisture will be measured via the GCS soil moisture sensor. 2. Datasheet

Specification 3.3.1.5 GCS Mode Toggling	
Text	All GCS variants shall be capable of toggling through set modes via a button interface connected to GPIO Pins.
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by demonstration.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. Button interface will switch the active GCS mode. 2. 3. Raspberry Pi Pico Button Guide

Specification 3.3.1.6 GCS Mode Display	
Text	All GCS variants shall be capable of displaying it's active mode via an Adafruit Standard HD44780 LCD Display.
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by demonstration.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. An LCD display will show the active GCS mode. 2. Datasheet

3.3.2 Network Processing

The network requirements for Garden Control System are listed below.

Specification 3.3.2.1 Network Types	
Text	All GCS variants shall be capable of ...TBD... network types.
Status	**Phase 1** Threshold
Acceptance	This requirement shall be verified by demonstration.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. Add as many of these as necessary. Split into files/folders, e.g., NetworkTypes.tex, NetworkInputs.tex, and NetworkOutputs.tex, etc. as needed. Just use the RequirementNumberAM and RqtNumberBase commands to keep numbers correct if subsubsections are added.

Specification 3.3.2.2 Network Inputs	
Text	All GCS variants shall be capable of ...TBD... network inputs.
Status	**Phase 1** Threshold
Acceptance	This requirement shall be verified by demonstration.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. Add as many of these as necessary. Split into files/folders, e.g., NetworkTypes.tex, NetworkInputs.tex, and NetworkOutputs.tex, etc. as needed. Just use the RequirementNumberAM and RqtNumberBase commands to keep numbers correct if subsubsections are added.

Specification 3.3.2.3 Network Outputs	
Text	All GCS variants shall be capable of ...TBD... network outputs.
Status	**Phase 1** Threshold
Acceptance	This requirement shall be verified by demonstration.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. Add as many of these as necessary. Split into files/folders, e.g., NetworkTypes.tex, NetworkInputs.tex, and NetworkOutputs.tex, etc. as needed. Just use the RequirementNumberAM and RqtNumberBase commands to keep numbers correct if subsubsections are added.

3.3.3 Power Processing

Specification 3.3.3.2 US Solar Pump B3A 5V PWM Circulating Pump Power	
Text	All GCS variants shall be capable of routing and supplying 5V of power to the US Solar Pump B3A 5V PWM Circulating Pump.
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by demonstration.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. Product Page

Specification 3.3.3.3 BME280 Temperature Sensor Power	
Text	All GCS variants shall be capable of routing and supplying between 1.2V-3.6V of power to the BME280 Temperature Sensor.
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by demonstration.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. Datasheet 2. BME280 Driver

Specification 3.3.3.4 I2C Capacitive Moisture Sensor Power Requirements	
Text	All GCS variants shall be capable of routing and supplying between 3V-5V of power to the BME280 Temperature Sensor.
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by demonstration.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. Datasheet

Specification 3.3.3.5 Adafruit Standard HD44780 LCD Power Requirements	
Text	All GCS variants shall be capable of routing and supplying between 2.7V - 5V of power to the Adafruit Standard HD44780 LCD.
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by demonstration.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. Datasheet

3.3.4 Control Processing

The control requirements for Garden Control System are listed below.

Specification 3.3.4.1 Water Pump Control	
Text	All GCS variants shall be capable of activating and deactivating a US Solar Pump B3A 5V PWM Circulating water pump.
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by demonstration.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. The Garden Control System will be activate/deactivate a US Solar Pump B3A 5V PWM Circulating water pump based on environmental data meeting thresholds or set time durations have passed. 2. US Solar Pump B3A 5V PWM Circulating Water Pump Product Page

Specification 3.3.4.2 Irrigation Mode Switching	
Text	All GCS variants shall be capable of switching it's active system mode via the GPIO button interface.
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by demonstration.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. The irrigation system mode will be able to change between Active Monitoring, Scheduled Irrigation, and Manual Activation.

3.4 Internal Interface Requirements

This section provides the internal interface requirements. As of now, there are no internal interface requirements for GCS.

3.5 Internal Data Requirements

This section provides the internal data requirements. As of now, there are no internal data requirements for GCS.

3.6 Adaptation Requirements

This section lists the adaptation requirements for the system. The GCS capability is segmented into the following specification groups:

Temperature Conversions describes the adaptation requirements pertaining to temperature measurements, § 3.6.1.

3.6.1 Temperature Conversions

Specification 3.6.1.1 Temperature Conversions	
Text	Temperature data measured must be capable of being converted to °F and °C
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by demonstration.
Traceability	**N/A** This is a base requirement.
Notes	1. Temperature can be converted between Farenheit and Celcius.

3.7 Safety Requirements

This section lists the safety requirements for the system. As of now, there are no safety requirements for GCS.

3.8 Security and Privacy Requirements

This section provides the security and privacy requirements for GCS. There are no privacy requirements for GCS. The GCS capability is segmented into the following specification groups:

Security Requirements provides the physical and cyber security requirements of the system, § 3.8.1.

3.8.1 Security Requirements

3.8.1.1 Cyber Security

Specification 3.8.1.1.1 Critical and High Vulnerability Findings	
Text	The Garden Control System shall not use any software packages or libraries that have critical and high vulnerability findings.
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by vulnerability scans.
Traceability	**N/A** This is a base requirement.
Notes	1. Vulnerability scans can be conducted by open source tools. Any critical or high vulnerability findings must be acted on and the vulnerability must be remediated. 2. List of Open Source scanning tools.

Specification 3.8.1.1.2 OWASP Top 10	
Text	The Garden Control System software development process shall avoid security concerns outlined in the OWASP Top 10.
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by vulnerability scans.
Traceability	**N/A** This is a base requirement.
Notes	1. The OWASP Top 10 is a regularly-updated report outlining security concerns for web application security, focusing on the 10 most critical risks. 2. OWASP Top 10

3.9 Environmental Requirements

This section defines the environmental requirements for GCS. The GCS capability is segmented into the following specification groups:

Temperature Requirements provides the physical and cyber security requirements of the system, § 3.9.1.

Waterproofing Requirements provides the physical and cyber security requirements of the system, § 3.9.2.

Altitude Requirements provides the physical and cyber security requirements of the system, § 3.9.3.

3.9.1 Temperature

Specification 3.9.1.1 Temperature	
Text	All Garden Control System variants shall be required to operate in temperatures between 0°F and 150°F.
Status	**Phase 1** Threshold
Acceptance	This requirement shall be verified by testing.
Traceability	**N/A** This is a base requirement.
Notes	1. The system is designed to operate outside and must be able to withstand a range of temperatures.

3.9.2 Moisture

This section is provided for future expansion.

Specification 3.9.2.1 Waterproofing	
Text	All deployable components of GCS shall be waterproof up to at least an IP65 waterproof IP Rating.
Status	**Phase 1** Threshold
Acceptance	This requirement shall be verified by inspection.
Traceability	**N/A** This is a base requirement.
Notes	1. An IP65 Waterproof rating is the minimum standard rating for outdoor equipment.

3.9.3 Altitude

This section is provided for future expansion.

Specification 3.9.3.1 Altitude	
Text	All deployable components of GCS shall be required to operate between sea level and 15,000 ft.
Status	**Phase 1** Threshold
Acceptance	This requirement shall be verified by inspection.
Traceability	**N/A** This is a base requirement.
Notes	1. This specification is to be met in conjunction with other segment specifications.

3.10 Technology Resource Requirements

This section provides the overall technology resource requirements for the system. These capabilities are divided into the following sections:

Hardware details about the hardware to be used.

Software details about the software to be used.

Communications details about the communications to be used.

Utilization details about the resource utilization.

3.10.1 Hardware Resources

This section provides the system computer hardware requirements.

Specification 3.10.1.1 Raspberry Pi Pico W	
Text	GCS shall be controlled by a Raspberry Pi Pico W microcontroller. The Pico W meets the necessary hardware requirements listed in the The KNEAD Project, *System Performance Specification for the KNEAD Example Project* [6].
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by demonstration.
Traceability	**N/A** This is a base requirement.
Notes	1. Raspberry Pi Pico W Datasheet

3.10.2 Software Resources

This section provides the system software requirements. As of now, there are no system software requirements.

3.10.3 Communications Resources

This section defines the computer communications requirements. As of now, there are no computer communications requirements.

3.10.4 Utilization Resources

This section provides the system technology resource utilization requirements. Specific requirements are presented for hardware, software, communications, and other technology resources. As of now, there are no system technology resource utilization requirements for GCS.

3.11 System Quality Requirements

SPS/SSS-3.11.0 :: This section shall specify the requirements, if any, pertaining to system quality factors. Examples include quantitative requirements concerning system functionality (the ability to perform all required functions), reliability (the ability to perform with correct, consistent results – such as mean time between failure for equipment), maintainability (the ability to be easily serviced, repaired, or corrected), availability (the ability to be accessed and operated when needed), flexibility (the ability to be easily adapted to changing requirements), portability of software (the ability to be easily modified for a new environment), reusability (the ability to be used in multiple applications), testability (the ability to be easily and thoroughly tested), usability (the ability to be easily learned and used), and other attributes.

This section specifies the GCS quality requirements.

3.11.1 Quality Systems

Specification 3.11.1.1 Software Quality	
Text	The system software must meet Capability Maturity Model Integration (CMMI) Level 3 standards.
Status	**Phase 1** Threshold
Acceptance	This requirement shall be verified by inspection.
Traceability	**N/A** This requirement is a base requirement.

This section provides the system quality requirements for GCS.

3.11.2 Operational Quality

This Section provides the operational quality requirements for GCS.

3.12 Design and Construction Requirements

This section provides the GCS design and construction requirements.

3.12.1 Regulatory Restrictions

This section is included for future expansion.

Specification 3.12.1.2 Proprietary Components	
Text	All Garden Control System variants shall include only software components that are open source or to which the developer has unlimited rights.
Status	**Phase 1** Threshold
Acceptance	This requirement shall be verified by inspection.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. The inspection is of the software design documents and build scripts to ensure that all code meets this requirement.

3.13 Personnel Requirements

This section provides all personnel requirements for GCS. As of now, there are no personnel requirements for GCS.

3.14 Training Requirements

This section provides training requirements for GCS.

3.14.1 Manuals

Specification 3.14.1.1 Operator's Guide	
Text	The GCS shall provide an operator's manual.
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by inspection.
Traceability	**N/A** This is a base requirement.
Notes	1. The Operator's manual will detail how GCS works.

Specification 3.14.1.2 Installation Instructions	
Text	The GCS shall provide detailed installation instructions.
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by inspection.
Traceability	**N/A** This is a base requirement.
Notes	1. There will be detailed installation instructions provided and with recommendations and best practices for setting up GCS. 2. There will be recommendations for how to install the drip irrigation tubing. 3. There will be recommendations for where to place the GCS sensors in a garden.

3.15 Logistics Requirements

This section provides the logistics requirements for GCS.

3.15.1 Support Constraints

Specification 3.15.1.1 Parts Replacement	
Text	The system contains parts and sensors that will be exposed to the environment. Garden Control System will support parts replacement for any damaged or malfunctioning parts
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by inspection.
Traceability	**N/A** This is a base requirement.
Notes	1. Certain parts for GCS will be replaceable. 2. Water Pump 3. Drip Irrigation Tubing

3.16 Packaging Requirements

This section provides the packaging requirements for GCS. As of now, there are now packaging requirements for GCS.

3.17 Other Requirements

This section provides other requirements for GCS. As of now, there are no other requirements for GCS.

3.18 Precedence of Requirements

This section details the precedence of requirements for GCS.

3.18.1 Safety

Specification 3.18.1.1 Safety Requirements Precedence	
Text	All Garden Control System variants shall meet safety requirements listed in Section 3.7 before all other requirements.
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by inspection.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. Obviously safety is of utmost importance. 2. The inspection is of design notes and rationale whereby design decisions relating to precedence are recorded.

3.18.2 Security and Privacy

Specification 3.18.2.1 Security Requirements Precedence	
Text	All Garden Control System variants shall meet security requirements listed in Section 3.8.1 before all other requirements with the exception of safety.
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by inspection.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. Security trumps privacy since good security should help ensure privacy. 2. The inspection is of design notes and rationale whereby design decisions relating to precedence are recorded.

3.18.3 Other

Specification 3.18.3.1 Other Requirements Precedence	
Text	All Garden Control System variants shall meet with equal precedence all other requirements not pertaining to safety and security.
Status	**All Phases** Threshold
Acceptance	This requirement shall be verified by inspection.
Traceability	**N/A** This requirement is a base requirement.
Notes	1. The inspection is of design notes and rationale whereby design decisions relating to precedence are recorded.

CHAPTER 4

Qualification Provisions

The qualification provisions are listed in the acceptance row of the specifications in Section 3.

CHAPTER 5

Traceability

This section provides a list of the sources, if applicable, for each requirement. This traceability connects the specifications in this document to those presented in higher level sources such as a Joint Urgent Operational Need (JUON) document, Joint Emergent Operational Need (JEON), or a STATEMENT OF WORK (SOW)

The traceability of all specifications from each requirement to its source, if applicable, is listed in the specifications presented in section 3. Traceability from each document to requirements is provided below.

Table 6: Source to Requirement Traceability.

Source Requirement	**Traced Requirement**
N/A :: This requirement is a base requirement.	3.11.1.1
N/A :: This requirement is a base requirement.	3.12.1.2
N/A :: This requirement is a base requirement.	3.18.1.1
N/A :: This requirement is a base requirement.	3.18.2.1
N/A :: This requirement is a base requirement.	**??**
N/A :: This requirement is a base requirement.	3.18.3.1

APPENDIX A

Notes

This section provides notes, as necessary, to document the system segmentation specification.

APPENDIX B

Key Performance Parameters and System Attributes

This Appendix provides the key performance parameters and key system attributes, summarized in a short list for easy review.

B.1 Key Performance Parameters

Table B.7: Key Performance Parameter Specifications

Specification	Key Performance Parameter
REF_UNDEFINED	The system shall provide the TBD Mode in the states and sub-states as shown in Table 4.

B.2 Key System Attributes

Table B.8: Key System Attribute Specifications

Specification	**Key System Attribute**
RQT_TBD	The system shall be capable of ...TBD... capability.