A GIS-based analysis of the status of streetlighting on the WCG road network: Towards a spatial asset repository to guide decision making and asset management

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Declaration

I, Jason P. Truter hereby declare that this thesis contains my original work completed by me and has not previously been submitted in this form to any institution.

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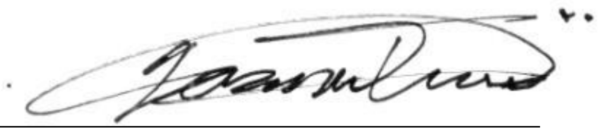
Signature:____

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Abstract

Background

The Western Cape Government (WCG) Roads Infrastructure Directorate oversees the management and maintenance of road network assets through systems like the Road network Information System (RNIS). However, streetlight data within the RNIS is incomplete, unverified, and lacks consolidation, limiting its utility for asset management and strategic planning. Accurate and comprehensive streetlight asset records are essential for supporting initiatives such as the Green Lighting program, which promotes LED retrofits to enhance lighting infrastructure quality and reduce energy consumption and running costs. Additionally, South Africa's rising electricity costs and scarcity necessitates efficient management of streetlighting infrastructure. GIS offers proven capabilities for spatial data management, analysis, and visualisation, making it a suitable tool for addressing these challenges. However, the absence of accurate and precise data, coupled with a lack of GIS-based analysis tools, hampers decision-making and planning efforts. This study aims to address these gaps by capturing, formalising, and transforming streetlight data into an actionable format to guide infrastructure management.

Aim

This study seeks to establish a comprehensive spatial dataset of streetlighting assets along the WCG road network and leverage GIS to inform decision-making processes. The primary objectives are:

- To create an improved and verified spatial dataset of WCG-maintained streetlight assets.
- To compile and visualise a conclusive streetlight repository, representing the current state of streetlighting.
- To demonstrate the application of GIS analysis in identifying areas of concern and prioritising resource allocation.
- To evaluate the suitability of GIS-based tools in enhancing strategic planning and infrastructure management.

The study will employ geomatics-based methods for data capture, integration of data into a GIS environment, and use spatial analysis to derive actionable insights related to streetlight density, extent, and alignment with complementary datasets. These outputs aim to optimise resource allocation and support the expansion and maintenance of streetlighting infrastructure along the WCG road network.

Method

The study employed a GIS-based methodology within the Esri environment to develop a mobile streetlight asset capture system and analyse streetlight infrastructure across the Western Cape Road network. Consumer-grade smartphones equipped with GNSS capabilities, and the Esri Field Maps application were used for field data collection, offering cost-efficiency, ease of use, and compatibility with existing WCG GIS infrastructure.

The application enabled geolocated streetlight data to be captured with 4-meter accuracy, and seamlessly integrate with the WCG ArcGIS Online environment, enabling the storage and live update of data in a Spatial Database Engine (SDE) geodatabase. Fieldwork, spanning two years, utilised a master feature class of existing streetlight records created through data aggregation and linear referencing, to guide data collection and verification. Challenges, such as GNSS accuracy and data gaps, were mitigated through strategic planning, supplemental remote sensing, and manual data edits.

Captured data was analysed through spatial techniques to provide actionable insights. Spatial analysis was structured into three components:

- Association of Related Attributes: Relationships between streetlights and the road network were established to create core datasets, forming the foundation for subsequent analyses and establishing the streetlight repository.
- Streetlight Analysis: Location-based GIS tools were employed to map streetlight distributions, analyse light coverage through buffer analyses, and assess light intensity using overlapping count methods.

- Road network Analysis: Geospatial techniques were applied to examine streetlight distribution along road networks, evaluate road illumination percentages, and perform density analyses (point and kernel density) to identify lighting patterns and hotspots.

Outputs comprise of comprehensive geospatial datasets, encompassing over 9300 streetlights and 900 traffic light sets. Analysis also resulted in various streetlight and road network-based datasets to supporting strategic planning and optimised roadway lighting management.

Results

This study successfully developed a GIS-based system for capturing and analysing streetlight data for the WCG Roads Directorate. It achieved its primary objective of creating a consolidated, verified streetlight asset repository, significantly improving data centralisation for infrastructure management. The data capture process, using ArcGIS Field Maps, integrated GNSS data into the GIS environment, effectively addressed challenges such as system integration and fieldwork inefficiencies. While technical limitations like intermittent offline functionality and GNSS accuracy were identified, the methodology proved highly practical for large-scale data collection. The analysis tools demonstrated GIS's ability to provide actionable insights, such as identifying areas with inadequate light coverage or intensity, while the web application allowed stakeholders to visualize and query streetlight data alongside other road infrastructure layers and related datasets.

Conclusions

The study validated GIS as a powerful tool for enhancing decision-making, asset visualisation, and strategic planning in the WCG Roads Directorate. It demonstrated that GIS can effectively support both short-term operational needs and long-term infrastructure goals by providing comprehensive, spatially referenced datasets and analysis capabilities.

The research offers a replicable model for integrating GIS into road asset management workflows, addressing challenges such as incomplete datasets and disconnected field operations. By facilitating data-driven decisions and optimising resource allocation, the system lays a strong foundation for future advancements in road asset management. This study also underscores the value of GIS in presenting data in interactive formats, supporting informed decision-making, and promoting efficient infrastructure planning and management practices.

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Glossary

ArcGIS Field Maps: An Esri mobile application used for field data collection of geolocated streetlight data, integrating with the WCG ArcGIS Online environment for live data updates. It simplifies complexities by integrating GNSS-collected data directly into the GIS environment, removing the need for post-processing and minimising data entry errors.

ArcGIS Online: The cloud-based environment used for housing and presenting spatial datasets. It is used in the study to establish a data tunnel with the WCG Roads Environment to overcome security limitations that block external internet access. It allows for map configuration and sharing with ArcGIS Field Maps.

ArcGIS Pro: Desktop software used for publishing the feature service and assigning symbology, which establishes a symbology template for features added in Field Maps. It also facilitates advanced GIS analysis functionalities.

Artificial Intelligence (AI) / Geo AI: AI simulates human intelligence in machines. Geo AI specifically focuses on spatiotemporal big data analysis through artificial intelligence to support optimal and automated decision-making in urban infrastructure planning, including roadway lighting. It could be used to optimise placement and operation of lighting assets, leading to reduced energy consumption and environmental impact.

Asset Management – Street/Traffic Lights Web Application: A web application which is a combination of the results of this study (datasets derived in chapter 6) and the originally developed application "Road Asset Management: Street/Traffic Light Poles" web application, which was used in the data capture phase.

Attribute Information: Non-spatial data linked to spatial features, such as the type, operational status, or unique identifiers of a streetlight. This data is essential for building a comprehensive asset register and enabling analysis.

Attribute-Driven Symbology: A method used in the study to visually distinguish between captured and uncaptured streetlight data by rendering captured features with 90% transparency, reducing visual clutter during fieldwork.

Buffer Analysis: A spatial analysis technique that creates buffer polygons around input features to a specified distance. In the study, Euclidean buffers were used at 22m and 28m to derive streetlight coverage, forming continuous coverage polygons.

Capture Feature Classes: Two primary feature classes created for the study: "StreetLights_Poles" for streetlights and "Traffic_Light_Pole" for traffic lights. These classes were designed to capture spatial location and unique identifiers, with attributes like 'Pole_ID' often left blank due to absence on physical poles.

Collection Accuracy: The desired precision for geolocated data capture. Initially set at 3.5m, it was adjusted to 4m due to difficulty in consistent achievement while moving in a vehicle, with the number of observations increased from 2 to 5 epochs to improve positional accuracy through averaging.

Comprehensive: At a thorough and complete level, including all or nearly all aspects of something. In the context it implies a broad and inclusive approach, covering everything relevant or necessary.

Device Independence: A key consideration for mobile data capture systems, ensuring compatibility across various devices (like iOS and Android smartphones) for flexible deployment.

Esri Environment/Suite: Refers to the Geographic Information System (GIS) software products and ecosystem developed by Esri, used extensively by the WCG Roads Directorate.

Existing Streetlight Locations: Records of streetlighting positions and sections, often incomplete or unverified, combined into a master feature class to guide fieldwork geographically. These records were derived from various sources and integrated into the ArcGIS Field Maps application as a visual reference.

Feature Class: A collection of geographic features with the same geometry type (point, line, or polygon) and attributes. Streetlight locations were captured as individual point features in a feature class called "StreetLights_Poles". They require specific default settings to allow editing and attachment of images.

Feature Service: A web service that serves feature data and nonspatial tables (attachments) over the internet or intranet, allowing the data to be used in web clients, desktop applications, and field applications. It must be configured to enable editability, synchronisation, or export.

Field Work: The process of collecting data on-site. It leveraged ArcGIS Field Maps to simplify data capture by integrating GNSS-collected data directly into the GIS environment. The fieldwork collected over 9,300 streetlights and 900 traffic light sets.

Geodatabase: The built-in data structure for Esri GIS products and the primary data format used for editing, data management, and analysis. It facilitates the storage of various types of data and supports advanced analysis functionality. The WCG uses a Spatial Database Engine (SDE) geodatabase for data interacting with ArcGIS Online.

Geographic Information System(s) (GIS): A powerful tool with proven capabilities for spatial data management, analysis, and visualisation. It has transformed spatial analysis, data management, and decision-making, proving instrumental in the built environment and beyond. GIS is highlighted in the study as an archive and monitoring system for roadway assets, enabling detailed spatial tracking of locations, conditions, and relationships to other infrastructure.

Geomatics-based Methods: The technical approaches employed by the study for data capture, integration of data into a GIS environment, and spatial analysis to derive actionable insights.

Global Navigation Satellite System (GNSS): Technology determining location based on satellite-transmitted data from various constellations like GPS, GLONASS, Galileo, and BeiDou. Consumer-grade smartphones with GNSS capabilities were used for field data collection, offering 4-meter accuracy.

GlobalID: A unique identifier automatically generated for each feature in the geodatabase.

Kernel Density: A spatial analysis tool that calculates a magnitude-per-unit area from point features by fitting a smoothly tapered surface to each point. It's used to identify "hotspots" or areas of higher density in the streetlight data.

Linear Referencing: A method for storing distance information related to a line feature, modelling relative locations along linear features. It is a standard way of generating features related to road sections in the RNIS.

Percentage of Road Illumination: An analysis calculating the total length of road segments illuminated by streetlights, then computing the percentage of road illumination per road.

Point Density: A spatial analysis tool that calculates a magnitude-per-unit area from point features within a neighbourhood68.

Pole_ID: An attribute initially intended for capturing unique identifiers of streetlight poles but found to be rarely present on physical poles and not serving to reference any existing WCG Roads Directorate dataset, leading to its removal from the feature class.

Proof of Concept: A demonstration of the feasibility of a method or idea. The GIS analysis in the study served as a proof of concept for demonstrating the value of using GIS to capture and analyse streetlighting assets.

Raster data: a type of spatial data that represents geographic information as a grid of regularly sized pixels or cells.

Remote Sensing: The process of acquiring information about an object or phenomenon without physical contact, often using satellite imagery or drones. The study used CoCT imagery to capture traffic lights in certain areas, proving highly effective.

Road Asset Management: Street/Traffic Light Poles Web Application: A ESRI GIS web application developed to monitor field work progress by consuming and displaying live feature classes used for streetlight capture. This web application is hosted and accessible via the WCG Roads ArcGIS Portal. It integrates various base maps and related data, such as aerial imagery and active project locations, to guide field capture planning.

Road Lighting Hotspots: Areas identified through Kernel Density analysis where streetlights are concentrated, indicating higher density or "hotspots" of lighting.

Road Logs: A format used by the RNIS to record road assets and associated data, attributing a rolling distance kilometre value to each feature along the road.

Road Network Information System (RNIS): An existing system used by the WCG Roads Infrastructure Directorate for managing road inventory and reporting on road characteristics and associated traffic data.

Road Number: a unique ID used to identify a particular road across all WCG Roads Systems.

Road Number Query: A task within the Road Network query that requires input of road type (e.g., 'District') and road number (e.g., '1001') to retrieve relevant road information.

Road Structure Query: A task within the Road Network query that requires input of structure number, description, and type code to retrieve information on road structures.

Road Streetlight Quantity: An analysis to establish the number of streetlights along each road based on spatial intersection with road buffers, providing a quantitative result with spatial context.

Segment ID: a unique ID used to identify a particular segment of a road (denoted by a road number) across all WCG Roads Systems.

Spatial Database Engine (SDE) Geodatabase: A type of geodatabase used in the WCG Roads Esri environment that extends a database management system (DBMS) (such as SQL) with spatial technology, offering benefits like data management, integrity, redundancy, accessibility, and security.

Spatial Data: Information related to geographic locations, which GIS is adept at managing, analysing, and visualising. The study focuses on capturing, formalising, and transforming streetlight data into an actionable spatial format.

Spatial Join Analysis: A GIS technique that joins attributes from one feature layer to another based on their spatial relationship (e.g., proximity or intersection). It was used to link streetlight locations with road network attributes.

Streetlight Density: Calculated using Point Density and Kernel Density analysis, providing values indicating the number of streetlights per unit area.

StreetLights_Poles: see Capture Feature Classes

Streetlight Repository: The comprehensive spatial dataset of streetlighting assets along the WCG road network established by the study, housed in the WCG Roads SDE database. It includes streetlight poles, traffic lights, and traffic light sets.

TMH Standards: Technical Manual for Highways standards, which the WCG requires its data systems to meet for quality and validity.

Traffic Light Sets: A feature class containing centroid locations for each traffic light intersection, manually digitised in Esri ArcPro as an accompanying dataset and undergoing spatial join analysis.

Traffic_Light_Pole: see Capture Feature Classes

Traffic Intersection Light Coverage: An analysis establishing the frequency of streetlights in the area surrounding an intersection, achieved by spatial join analysis using a 28m join radius around intersection centroids. This provides a quantitative measure of light coverage per intersection.

Vector data: a type of spatial data that represents geographic features as points, lines, and polygons, defined by their spatial coordinates (x, y, and sometimes z).

Web Application: A software application accessible via a web browser. A dedicated web application named 'Road Asset Management: Street/Traffic Light Poles' was developed to monitor field work progress and display live feature classes.

Western Cape Government (WCG) Roads Directorate: The entity responsible for overseeing the management and maintenance of the road network assets in the Western Cape.

1. INTRODUCTION

1.1 Background to Investigation and Problem Statement

The Western Cape Government (WCG) Roads Infrastructure Directorate maintains various systems relating to the asset management and maintenance of the road network. The Road network Information System (RNIS) deals with the management of road inventory and reporting on road characteristics and associated traffic data. RNIS contains a record of road assets, furniture and structures, constituted and captured in the form of Road Logs which attribute a rolling distance km value to each feature along the road. Currently streetlights are represented by incomplete, unverified and unconsolidated non-spatial datasets covering partial portions of the network.

The effective and efficient management and maintenance of streetlights as-well-as the strategic planning for improving street lighting infrastructure, necessitates a complete, consolidated and ground-truthed asset record. The widespread adoption of a Green Lighting imitative has driven LED lighting retrofits in an effort to improve lighting quality, reduce electricity consumption and gain environmental benefits. This drive has prioritised the need for an accurate streetlight asset record. Further, the increasing cost and scarcity of electricity supply in South Africa priorities the need for every aspect related to electricity to be managed as efficiently as possible. Geographic Information System(s) (GIS) presents both opportunities and proven results as a tool to enable and support efficient and effective management of spatially attributed data such as streetlights.

Advancements in technology in the realms of machine learning and Narrow AI allow for exciting optimisation in several management applications of WCG Roads Infrastructure Directorate – but at the core is a need for good data. In terms of the scope of this research the current data environment faces two challenges: the lack of complete and verified data and the lack of analysis tools, in terms of streetlights and potentially relevant and complementing assets or data.

Established practices exist for generating GIS datasets from RNIS Road logs, however the existing entries for streetlights do not only lack validity but are based on the liner extents of road section (lacking precision due to resolution), rather than being represented by point features with improved precision. The lack of accurate and ground-truthed data nullifies any GIS analysis result or support it could offer in strategic decision making or management planning. Despite streetlight data sources existing in some form, there is a clear need to capture, formalise and transform the data, to enable, and conduct accurate analysis that can guide decision makers.

1.2 Purpose and Aims

1.2.1 Purpose of Research

The purpose of this investigation and resulting dissertation is to establish the level and extent of streetlighting along the Western Cape Government Road network and develop spatial data driven tools that inform decision-making to improve and manage streetlighting. By employing geomatics-based methods, effectively capture relevant outstanding assets and compile data in a GIS environment. Further, making use of GIS analysis, produce results related to density, extent, coverage and alignment with related data. The results derived should inform technical and strategic planning and decision making to optimise resource allocation in the expansion and maintenance of streetlight infrastructure.

1.2.2 Research Objectives

The research has two objectives which inform the four aims respectively. The primary objective is to capture and compile a comprehensive asset record of streetlighting along the WCG road network, determine the current state of streetlighting and visually represent the resulting streetlight repository in the GIS environment. The secondary objective is to evaluate the effectiveness of GIS as a tool for analysing an interrogating all information pertaining to the lighting installation on the WCG road network.

1.2.3 Research Aims

The study has four aims:

- Firstly to establish an improved and verified spatial dataset of WCG maintained streetlight assets. This includes the integration of existing resources, and field verification and capture, of street light asset points. The Verification and capture of data will necessitate the development of a capturing methodology and capture tool. This will take the form of a GIS-based capturing system that integrates spatial data and asset attributes for streetlighting.
- Secondly, to produce and visualise a definite streetlight repository, representing the state of streetlighting along the WCG road network. The datasets that constitute this repository should reside in the WCG GIS environment and be accessible to web-based application in the environment.
- Thirdly, to establish a proof of concept demonstrating the application of GIS analysis of the streetlight assets by means of GIS tools and methods. , that The analysis will focus on providing results that can inform management processes and resource allocation.
- Finally, to demonstrate, through the review of the GIS analysis results and data management methods, that the application of GIS can guide decision makers to areas of concern and inform strategic lighting asset management.

The conclusion will evaluate the efficiency of the methods employed for data capture and the relevance and applicability of the findings and results from GIS analyses and its replicability.

1.3 Scope

The scope of this study encompasses the spatial data capture and GIS-based analysis of streetlighting across the WCG road network. Specifically, it aims to address the lack of understanding of the state of streetlighting and the current deficiencies in datasets maintained by the WCG Roads Infrastructure Directorate. These datasets are incomplete, unverified, and lack consolidation, thereby hindering effective asset management and strategic planning for streetlight infrastructure. The study will focus on:

- Data capture methods, management and accessibility: Deriving and evaluating a suitable method for capturing and verifying streetlight assets to establish a comprehensive and accurate dataset in the context of the WCG GIS environment. Determining optimal data formats, storage practices, and accessibility measures for maintaining the streetlight asset record within the WCG road network context.

- GIS analysis: Conducting spatial analysis using GIS techniques to assess the current state of streetlighting infrastructure. This includes examining the coverage, spatial distribution, and lighting conditions along the road network.

- Strategic planning and decision making: Provide GIS outputs in a form that can inform decision makers about priority areas for streetlight improvements and lighting conditions along the WCG road network.

The study may incorporate other spatial data such as satellite imagery and topographic data for visualisation. The narrow and specified nature of the investigation is due to the focused and specific needs of the WCG Roads Directorate and the context of the existing enterprise GIS environment.

1.4 Methodology

This section outlines the methodology adopted for this study detailing data collection, spatial database design and implementation, quality assurance and control, and web based and desktop analysis and visualisation. While Chapters 3, 4, and 5 of this dissertation communicate the specific methods employed for data acquisition and system development, and Chapter 6 elaborates on the specific analytical methods employed, this introductory methodology section provides a concise overview of what was done and explains the rationale behind each methodological choice, aligning it with the study's stated objectives.

The research employs a GIS-based methodology within the Esri environment to develop a mobile streetlight asset capture system and subsequently analyse the streetlight infrastructure across the Western Cape Road network. This approach was selected due to GIS's proven capabilities for spatial data management, analysis, and visualisation, which are essential for addressing the challenges of incomplete, unverified, and unconsolidated streetlight data within the WCG Roads Directorate's Road Network Information System (RNIS).

The methodology is structured to directly address the primary aims of the study:

1.4.1 To Create an Improved and Verified Spatial Dataset of WCG Maintained Streetlight Assets

1.4.1.1 Data Collection Methods and Quality Assurance/Control

The study utilises consumer-grade smartphones equipped with GNSS capabilities and the Esri Field Maps application for field data collection. This approach offers cost-efficiency, ease of use, and compatibility with existing WCG GIS infrastructure. Spatial geolocated streetlight data is captured with application that seamlessly integrates with the WCG ArcGIS Online environment for storage and live updates in a Spatial Database Engine (SDE) geodatabase. Fieldwork, conducted over two years, was guided by a master feature class of existing streetlight records (aggregated from contractor reports and archived RNIS data) to direct data collection and verification. To ensure data quality, the collection accuracy was set to a maximum of 4m, and the number of GNSS observations (epochs) was increased from 2 to 5 for averaging readings, which mitigates challenges with consistent accuracy, especially when moving in a vehicle.

1.4.1.2. Data Verification and Mitigation

Challenges such as GNSS accuracy variations (e.g., during midday in summer or in mountainous areas) and data gaps were addressed through strategic planning, supplemental remote sensing (e.g., using City of Cape Town imagery for traffic light capture in dangerous areas), and manual data edits in Esri ArcMap for points missed due to connectivity issues.

1.4.2 To Produce and Visualise a Definite Streetlight Repository, Representing the Current State of Streetlighting

1.4.2.1 Spatial Database Design and Implementation

The core of the data repository is built upon Esri's geodatabase structure, specifically implemented within a Spatial Database Engine (SDE) geodatabase in the WCG Roads GIS environment. This allows for robust data management, integrity, redundancy, accessibility, and security. Feature classes (e.g., "StreetLights_Poles", "Traffic_Light_Pole") were created to store individual point features and their attributes.

1.4.2.2 Attribute Association

Post-capture, a crucial step is spatial join analysis to link streetlight locations with relevant attributes from the WCG road network and street datasets, such as Road Number, Segment ID, and Town Names. This enriches the raw spatial data, making it suitable for querying and further analysis, and constitutes the foundation for the comprehensive streetlight repository.

1.4.2.3 Web GIS for Visualisation and Monitoring

The WCG organisational ArcGIS Online environment is leveraged to overcome domain security limitations, establishing a data tunnel for live synchronisation between ArcGIS Online and the WCG Roads Environments. Feature services are published from the SDE geodatabase to enable data consumption by ArcGIS Field Maps and to power web applications. A dedicated web application, 'Road Asset Management: Street/Traffic Light Poles', is developed and hosted on the WCG Roads ArcGIS Portal to display live captured feature classes, allowing for real-time monitoring of fieldwork progress and offering visual context with various base maps and related data (e.g., aerial imagery, active project locations). This web application is later redeveloped into 'Asset Management – Street/Traffic Lights' to incorporate enhanced data and functionalities, serving as a primary tool for visualising the streetlight repository and facilitating queries.

1.4.3 To Establish a Proof of Concept Demonstration of the Application of GIS Analysis that can Guide Decision Makers to Areas of Concern

Spatial Analysis Techniques (Chapter 6 Rationale): The analysis phase, detailed in Chapter 6, was designed to provide actionable insights by transforming captured data into meaningful information for strategic planning and decision-making. This involves:

1.4.3.1 Association of Related Attributes

This foundational step (also described above) is critical for linking streetlights to the road network, which is the primary operational context for the WCG Roads Directorate, thus enabling subsequent road-focused analyses.

1.4.3.2 Streetlight Analysis

Location-based GIS tools are employed to map streetlight distributions (e.g., visualising streetlights over Esri World imagery and the WCG road network). Light coverage is assessed through buffer analyses (e.g., 22m and 28m Euclidean buffers) to identify areas lacking illumination. Light intensity is evaluated using overlapping count methods on these buffers to quantify regions of varying brightness, despite relying on general illumination assumptions due to a lack of specific fixture data. Traffic intersection light coverage analysis uses spatial joins to quantify streetlight frequency around intersections, enabling the classification of intersections by lighting sufficiency. These analyses provided a "proof of concept" for GIS's ability to identify areas of inadequate coverage or intensity.

1.4.3.3 Road Network Analysis

Geospatial techniques are applied to examine streetlight distribution along road network. This component aims to provide quantitative data aligned with the WCG Roads Directorate's focus on road segments. Road streetlight quantity is determined by the spatial intersection of streetlight features with road buffers. Percentage of road illumination is calculated by intersecting road sections with light coverage polygons. Density analyses (both point and kernel density) are performed to identify lighting patterns and "hotspots" along the road network. These analyses provided quantitative data and visual representations to inform decision-makers about the status of roads in terms of lighting infrastructure, directly supporting strategic planning and resource allocation.

1.4.4 To Evaluate the Suitability of GIS-based Tools in Enhancing Strategic Planning and Infrastructure Management

The entire methodology, from data capture to advanced spatial analysis and visualisation through web applications, is designed to demonstrate GIS's practical utility in overcoming existing data deficiencies and supporting informed decision-making for road asset management. The review of findings aims to show GIS's ability or inability to support both short-term operational needs and long-term infrastructure goals.

The detailed methods and review of literature that informs them, is further elaborated in the subsequent chapters. These chapters delve into the comprehensive approach taken to capture, store, analyse, and visualise streetlight data, ensuring its integrity and applicability for informing critical infrastructure management decisions within the Western Cape Government.

2. LITERATURE REVIEW ON GIS MAPPING AND ANALYSIS OF ROADWAY LIGHTING

2.1 Study Focus of this Literature Review

This literature review explores the development, implementation and benefits offered by a GIS-based system for capturing and analysing streetlight assets. The Western Cape Government's current records of streetlights are fragmented and inconsistent, leading to inefficiencies in asset management and maintenance. This literature review aims to address these challenges by exploring how GIS technology can be leveraged to compile an accurate and comprehensive asset register, supported by a robust GIS database from which GIS analysis can be driven.

Ther primary objective of the study is to develop and employ a GIS-based capturing system to create a comprehensive asset register and GIS database for streetlights along the WCG road network. Considering this, the literature presented aims to inform the design and implementation of a GIS-based capturing system that integrates spatial data and asset attributes for streetlights. Particular considerations are the means, effectiveness, and value of implementing such a system. As well as literature that examines GIS tools and data collection methods in terms of ensuring consistency and reliability in location information and data management.

Sections 2.2.2 addresses this by exploring literature related to the application of GIS in roadway lighting with a focus on the implementation of inventory mapping through mobile data capture. Section 2.2.4 presents the challenges to a GIS raised in literature, specifically focusing on data accuracy, integration and implementations constrains both technologically and organisationally. Section 2.2.6 reviews a case study presented in literature, in which streetlight data was captured and analysed, leading to results that could inform decision makers. This case study also presents analysis tools that pertain to the secondary study focus.

The secondary objective takes the form of an investigation into GIS-based analysis and presentation of results which can enhance strategic and technical planning, maintenance scheduling, network expansion and decision-making for managing streetlight infrastructure. Considering this, the literature presented aims to inform the development of GIS-based analysis tools relating the WCG road network and streetlights, in ways that offer support in technical and strategic planning and decision-making, for streetlight management.

Section 2.2.2.3 reviews GIS spatial analysis techniques which literature defines valuable in streetlight analysis. Section 2.2.3 focuses on the benefits identified in literature which a GIS and streetlight dataset offers in terms of monitoring and management. Section 2.2.5 discusses the potential advances in the GIS that can be harnessed in the WCG context through improved methods, employing automation and artificial intelligence to reduce environmental impact and promote sustainability.

While broadly based, the literature review intends to provide insights into the practical application of GIS for asset management and offers recommendations on the suitability of a GIS-based system for streetlight asset data capture and management. The study ultimately aims to present a solution to the current fragmented state of streetlight records by demonstrating how a GIS-based system can streamline asset capture, management, ensure data accuracy, and support both in long term strategic planning strategies, and monitoring and technical planning.

2.2 Review of Previous Research

2.2.1 GIS Applications in Roadway Lighting Analysis

GIS has played a transformative role in spatial analysis, data management, and decision-making processes at all levels. GIS has proven to provide spatial analysis capabilities that are instrumental in asset infrastructure, and specifically street lighting projects. This is substantiated by several studies that have demonstrated the utility of GIS in various domains.

2.2.1.1 Mapping and Inventory:

GIS allows for comprehensive mapping and inventory of streetlights, including their type, location, and operational status (Wollaston, et al., 2016) (Cheng, et al., 2020) (Xhafa & Kosovrasti, 2015). GIS, as an archive and monitoring system, is pivotal for managing roadway assets like streetlights, as it allows for detailed spatial tracking of their locations, conditions, and relationships to other infrastructure (Xhafa & Kosovrasti, 2015). Capturing and mapping of precise geolocation data and infrastructure attributes in GIS, forms the foundation for subsequent analysis and decision-making processes, as well as being essential for building a comprehensive asset register. (Sousa, et al., 2022) (Xhafa & Kosovrasti, 2015).

Vanier (2004) considers the application of GIS in asset management, and outlines how GIS integrates spatial data, such as location, asset types, and conditions, to produce "smart maps" which enable visualisation, analysis, and decision-making (Vanier, 2004). GIS has practical applications in the mapping of streetlights and other roadway assets, where spatially linking infrastructure data with conditions and attributes, like road type and traffic patterns or accident data, can inform maintenance strategies and network expansion prioritisation.

Xhafa & Kosovrasti (2015) highlights the ability of GIS to integrate large volumes of spatial data, providing planners with a powerful tool for manging large collections of network assets. Streetlighting presents a large dataset which GIS is suited to support in terms of enabling analysis, asset maintenance tracking, monitoring of energy consumption, and optimising streetlight placement in a large context to improve efficiency. The integration of larger data sets in a spatial context allows for detailed modelling and mapped simulation (digital twin creation), which can lead to better decision-making related to streetlighting infrastructure (Xhafa & Kosovrasti, 2015).

Alhamwi (2021) developed, FlexiGIS-light, a modular and open-source GIS application that models urban street infrastructures and simulates electricity consumption under different operational and renewable energy scenarios. Their paper demonstrates the use of open-source datasets like OpenStreetMap (OSM) to extract street networks and related data, which reveals the utility of publicly available data for replicating realistic urban infrastructure. This suggests the potential of adding value through interrogation (spatial audits) of established data records, within the GIS environment, leveraging public data to enhance the current WCG asset inventory.

Alhamwi (2021) demonstrates how GIS can be used to create accurate, spatially referenced models of streetlight networks, through detailed mapping and simulation of streetlight network infrastructures in Berlin. Alhamwi (2021)'s tool (using GIS techniques) provides a spatial understanding of where streetlights are located and how they interact with other urban infrastructures, enabling city planners to visualise energy consumption patterns and simulate future infrastructure scenarios. This practically demonstrates the proposals of Xhafa & Kosovrasti (2015) and echoes their sentiments that foundational spatial data mappings are key in roadway lighting analysis, which in turn is critical for urban planning, maintenance, and energy management (Alhamwi, et al., 2021).

The value of GIS-based roadway asset management is also emphasised by Murray & Feng (2016) who recognises the need for systematic planning, as traditional streetlight placement often lacks spatial efficiency. The introduction of spatial optimisation methods offered by GIS adds a significant improvement in this domain, offering a practical approach for analysing streetlight distribution (Murray & Feng, 2016).

2.2.1.2 Process of Mobile Data Capture Development and Implementation.

Nielson (2013) described the transition from a manual data capture process to the implementation of a mobile data capture system, as an arduous task. Nielson notes that the various technologies, providing options for digital data capture, are rapidly advancing making it difficult to predict the long-term suitability of a business solution. Industry has overcome the challenges related to device management, software capability and data integration.

However, the contemporary focus must be on the mobilisation or consolidation of various technologies in the organisational environment, in a manner that offers a sustainable business solution (Nielson, 2013).

To illustrate this necessity, Nielson describes an example of a company engaging a consultant to develop software for a specific mobile device. At development the system served its purpose and continued to do so without any changes over 4 years, yet at this point the devices were no longer supported, and operating systems were outdated. When the devices started to break down a blanket system upgrade of software and device was required. The WCG Road Systems faces these very issues with a custom application developed for an older version of Android, which is used to conduct road panel inspections. Nielson states that key considerations when implementing a mobile data capture system are the device and software:

- Device suitability is foremostly based on technical specification (GPS/GNSS accuracy, memory and processing power), with GNSS accuracy requirement being the most pertinent, and met by most current generation devices (Nowak, et al., 2020) (Dabove, et al., 2020). Device suitability is further based on useability factors including: use case (indoor or outdoor), resistance to environmental elements, size and clarity in terms of readability (can it be read in the sun) and portability (handheld or vehicle mounted), shock resistance and serviceability (Nielson, 2013).

- Nielson concludes that while filed specific ruggedized devices offer advantages in terms of durability, they lack features required in daily use, relatively lite duty use these devices see, additional cost and lagging technology when compared to mainstream devices, makes them unnecessary. Modern smart phones offer cutting edge technology and when paired with shock and waterproof cases offer a far more compact and ergonomic multifunction device than ruggedized tablets - often at a lower cost (Nielson, 2013). Currently the WCG Road Systems aims to accommodate both iOS (Apple devices) and Android mobile operating systems (OS), Nielson (2013) found that these are the dominant OS’s.

When evaluating a software application selection needs to consider several key points:

- The system needs to be able to work offline – The vast expanses of Queensland where Nielson's study is based are similar to regions in the Western Cape, in terms of the lack of ubiquitous network coverage at this point in time. As such the mobile system needs to be able to work offline and re-sync when re-entering an area with network coverage (Nielson, 2013). In mobile environments, maintaining constant connectivity is not always feasible. Therefore, it is important to implement a client-side mechanism that allows mobile workers to perform tasks in a disconnected mode (Huff, et al., 2000).
- Data loss prevention – a capture system should contain built in failsafe to prevent data loses (in case of device or server failure or signal lose) as this would negate advantages over manual processing (Nielson, 2013).
- Software should be platform independent and be transversal across OS's. This facilitates the 'Bring Your Own Device' scenario allowing for platform independence and interchange (Nielson, 2013).
- The system needs to improve on paper-based capture – the application must not simply be a digital version of the paper template but offer more in terms of processing and data integration (Nielson, 2013).
- Supported and maintained – the application must be supported by a consolidated software environment that can leverage capabilities for integration and accessibility (to devices or data) through scale. While custom applications for specific projects my leverage opensource or SDKs from establish GIS software providers, they should still be maintained by a reputable developer (Tomczuk, et al., 2021).

Currently Esri, QGIS, SAP, Microsoft, Bentley Systems and various other vendors offer off-the-shelf mobile applications that could possibly be suitable to streetlight asset capture. Nielson highlights that software packages generally lack integration cross-platform, requiring expensive custom ETL tools to share complete datasets. This serves as motivation to trial an application that aligns with existing platforms or software environments. Nielson's study continued with Esri applications, as their corporate GIS environment is Esri based, resulting in the seamless integration of data (Nielson, 2013). The WCG makes use of the Esri environment, with all existing GIS systems based in Esri products. Literature suggests the Esri software and environment is well suited to assets and spatial data analysis related to roads, having been implemented in several studies (Moscovivi, et al., 2022) (Alkhadour, et al., 2021) (Nielson, 2013).

2.2.1.3 Spatial Analysis Techniques

GIS enables spatial analysis to assess lighting coverage and identify various types of gaps. Techniques such as Proximity Tools (buffer analysis), heat and hotspot mapping, pattern analysis and spatial statistics are frequently used to analyse and interrogate spatial data, with a compelling exampling being the visualisation of lighting coverage and distribution in (Saraiji, et al., 2016) (Mitchell, 1999). Using these GIS tools in a temporal and spatial framework can reveal distribution patterns over time, providing insights into changing external attributes (Alkhadour, et al., 2021). Data collection tools and analysis methods are required to be replicable, to assure results are not influenced and data integrity is maintained (Tomczuk, et al., 2021). GIS can serve as a means of developing such a system-infrastructure that offers a facility for interpreting street lighting, in terms of coverage, spatial statistics and spatial optimisation, in relation to transversal data or temporal data (asset changes over time) (Pain, et al., 2006) (Feng & Murray, 2017).

2.2.2 Applications and Benefits

The literature offers valuable insights into the integration of GIS across a variety of fields, highlighting its capacity to manage, archive, and analyse spatial data to improve planning, infrastructure management, and sustainable development (Xhafa & Kosovrasti, 2015). GIS maps, models, and tools, can offer planners a systematic informed means of identifying areas with insufficient lighting coverage, the ability to predict future needs based on integration of related data (demographic growth, traffic), and assist in design optimisation of lighting solutions (Xhafa & Kosovrasti, 2015).

Masser & Ottens (2019) evaluates key implications for GIS in public infrastructure projects in terms of plan-making and administrative traditions:

- In terms of Plan-making, GIS offers solutions for specific urban infrastructure projects where there is a need to evaluate conditions, plan upgrades, or model changes in a temporary, task-oriented project. Task-oriented projects benefit from the focused, task-specific nature of GIS, allowing for detailed spatial analysis, lighting model simulations, and visual presentations to inform decision-making (Masser & Ottens, 2019).
- Administrative tradition would relate to long-term management and strategic planning of roadway lighting assets. A multi-user, multi-purpose GIS system would facilitate ongoing maintenance and updates to a lighting asset database, ensuring that data remains current and supports various operational levels (Masser & Ottens, 2019).

GIS offers a platform for the integration of technologies, such as GPS, diagrammatic data, and remote sensing, that can enhance data accuracy and asset tracking (Vanier, 2004) (Alhamwi, et al., 2021). This ability meets the need for integration of different data types, quality assurance processes, and metadata to assist diverse users which is crucial for managing assets over time and responding to both immediate operational concerns and broader strategic planning (Masser & Ottens, 2019). Vanier (2004) highlights examples where municipalities have leveraged GIS to manage roadway systems (manage roads, drainage, pipelines, and utilities) more effectively by integrating GPS-collected data on the positioning of assets and monitoring their conditions through real-time updates (Vanier, 2004).

Xhafar & Kosovrasti (2015) builds on these findings by noting the key benefit of GIS is its ability to facilitate data-driven decision-making. This is particularly relevant for roadway lighting, where real-time spatial analysis can inform immediate actions, such as emergency repairs or upgrades to energy-efficient lighting. Furthermore, GIS's analytical capabilities support long-term planning, enabling authorities to design sustainable public lighting strategies that reduce costs, lower energy consumption, and enhance safety for road users (Xhafa & Kosovrasti, 2015).

2.2.2.1 Monitoring, Visualisation and Query Support

Systems employing GIS and spatial database technology offer great innovation over traditionally paper-based models used to monitor streetlights - providing numerous benefits for roadway asset management and planning (Vanier, 2004) (Masser & Ottens, 2019) (Xhafa & Kosovrasti, 2015). A streetlight monitoring system based on GIS can maintain data through relational databases, which can provide streetlight status and distribution via a visual interface. This interface and its real-time query integration promotes informed decision making (Liu, 2017).

Vanier (2004) advocates the key benefit of GIS is the decision support it provides. In terms of streetlighting, this decision-making capability would help in prioritising maintenance, optimising placement for safety, and budgeting for upgrades based on spatially integrated data-driven decision-making (Vanier, 2004) (Xhafa & Kosovrasti, 2015). To facilitate and leverage spatial data-driven technology at scale, an enterprise level GIS, which allows for centralised data management and real-time updates, is required (Vanier, 2004). Centralised and connected data management's main benefit is large-scale management of assets across municipalities/ regions and the ability to share and integrate other sources of data throughout the intuition or infrastructure domain. While GIS supports large scale data integration, there is no limitation in monitoring, visualisation or querying of data at any scale (or aggregation). The system's ability for analysis at a granular level, or an assets localised area, is not hinder by the overall system data (both local or related) (Alhamwi, et al., 2021).

2.2.2.2 Safety and Crime Prevention

Several studies have explored the correlation between roadway lighting and the potential impact on safety. GIS-based analysis is strongly advocated as a tool that can assist in evaluating the relation and potential impact of lighting on accident rates and crime prevention:

Accident Analysis:

- Improved lighting and proper maintenance of streetlights can reduce road accidents, particularly at intersections and pedestrian crossings (Jimee, et al., 2022).

- Leveraging the GIS for relational analysis, can identify high-risk areas and evaluate the effectiveness of subsequent lighting interventions (Jimee, et al., 2022). Relational analysis can guid decisionmakers in identifying and prioritising corrective measures to critical areas, thus most effectively minimising accidents (Gupta, et al., 2022). With an accurate spatial model of streetlights, detection distances and glare blocking can be modelled and inform technical planning, ensuring illumination is not undermining sight distances (Saraiji, et al., 2016).

Crime Reduction:

- Well-lit streets are often associated with lower crime rates (Rea, et al., 2009) (Wollaston, et al., 2016). GIS analysis has been used to study the relationship between lighting levels and crime statistics, providing evidence for strategic placement of lighting assets to create "safer" spaces. The application of GIS promotes more inclusive knowledge (multiple data source integration) and more effective decision making, planning and operations - all critical to crime prevention policy research (Pain, et al., 2006).

2.2.2.3 Energy Efficiency and Cost Management

Literature finds GIS critical in optimising the energy efficiency of roadway lighting systems, which is of great interest to the WCG particularly due to the current context of South Africa, which faces significant challenges in terms of electricity supply constraints and limited government funding. With rising energy costs and load shedding impacting municipalities, GIS enables the efficient management of streetlight assets by mapping and analysing energy consumption patterns.

Energy Consumption:

- By analysing spatial data attributes, GIS can aid in deriving energy consumption patterns of different lighting technologies and identifying opportunities for energy savings (Fichera, et al., 2016). Spatial mapping and modelling will allow for light intensity planning and a dimming schedule system to cut energy consumption (Tagliabue, et al., 2020) (Wollaston, et al., 2016).

- The concept is practically illustrated by Alhamwi (2021) where GIS is used in energy consumption analysis, determining more energy efficient management methods, and the potential for integrating renewable energy sources, such as solar and wind, into the network. This is achieved through GIS simulation of various operational modes (e.g., operating streetlights for a full night vs. partial night illumination), which identified how municipalities can manage streetlights more energy-efficiently. They found GIS analysis and mapping is a key driver towards achieving energy self-sufficiency in urban street lighting (Alhamwi, et al., 2021).

Cost-Benefit Analysis:

GIS supports cost-benefit analyses by allowing the integration and attribution of data on lighting costs, maintenance, and energy usage. This allows the evaluation of economic feasibility of upgrading or retrofitting lighting systems. The innovation GIS implementation offers through visualisation, integration, analyse, and monitoring of asset data, offers benefits to management and maintenance not achievable with traditional tabular data.

While Government is sensitive to cost, they prioritise accountability over the financial returns of their assets. This can prove difficult to quantify, when traditional asset management systems focus on deriving a valuation of public infrastructure assets through historical cost, current replacement cost, and life-cycle cost analysis (Lemer, 1998). Lemer (1998) suggests these valuation methods often fail to capture the full societal, environmental, and economic benefits that infrastructure assets provide. They suggest a holistic view of "full-value management," to appropriately reflect the real impact of infrastructure on the communities they serve (Lemer, 1998). Lemer (1998) alludes to GIS being a key aspect of Infrastructure Information Management Systems that facilitate these holistic views.

While Enterprise GIS systems can be costly, the efficiency gains in benefits far out ways the implementation costs (Khakurel, 2024). Further, GIS is well supported by open-source tools and data which promotes transparency and accessibility at no access cost. Open-source or shared data facilitates also promotes collaboration between stakeholders locally and globally, unlocking shared knowledge and information - potentially reducing the need for costly proprietary data (Alhamwi, et al., 2021).

2.2.3 Challenges and Limitations

2.2.3.1 Data Accuracy and Integration:

One of the primary challenges in GIS-based roadway lighting analysis is ensuring the accuracy and integration of data particularly when continuous data updating and integration across various systems is required (Xhafa & Kosovrasti, 2015). Garbage in, garbage out, or GIGO, refers to the idea that in any system, the quality of output is determined by the quality of the input – a concept particularly relevant to GIS and GIS data quality (Heazlewood, 2015). While this is not a problem unique to GIS, it deserves particular attention due to the automation and unsupervised information creation GIS offers, which makes it difficult to naturally observe errors. In the context of roadway lighting, the accuracy of the underlying spatial data and incomplete or outdated data, can lead to errors in streetlight asset management, such as placement errors or overlooking areas that require increased coverage.

Data Collection and Quality:

- Inaccurate or outdated data can significantly affect the outcomes of GIS analyses. The WCG requires their data systems to be populated with verified data to meet relevant TMH standards. Studies emphasise the foundation and starting point of any GIS or asset management program is quality data. The need for regular updates, field validation and consistency in attributes of inventory data is key to informed reporting and decision-making (Hector-Hsu, et al., 2012).

Data Integration:

- Integrating urban datasets (e.g., traffic accidents, crime reports – multisource, multi-thematic and heterogeneous) within GIS (while GIS is well suited to data integration) can be complex (Mohammadi, et al., 2010). Ensuring compatibility and consistency across different data sources remains a challenge but is necessary as re-collection or conversion of data can present major obstacles (Vanier, 2004). Setting data collection standards and adopting national standards can reduce cost implications and complexity issues when integrating data from disparate systems (Hector-Hsu, et al., 2012). While the accommodation of temporal data has greatly improved, the integration of 3D capabilities in GIS is still in its infancy. This is compounded by the lack of object orientated modelling (BIM) available to comprehensively represent the complexity of infrastructure assets (Vanier, 2004). In the context of streetlights, the WCG does not require digital-twin levels of modelling.

2.2.3.2 Technological and Resource Constraints

Implementing GIS-based solutions for street lighting can require significant technological and resource investments. The cost of maintaining the GIS infrastructure and training personnel can be a significant barrier for some municipalities, especially in developing regions (Xhafa & Kosovrasti, 2015). The complexity of managing multi-thematic data can be a challenge, especially when integrating diverse data sources like satellite imagery, cadastral data, and asset registers. For streetlighting systems, combining data from multiple sources (e.g., traffic data, lighting usage, and energy consumption) can be demanding in technical skills and require advanced GIS tools and expertise (Xhafa & Kosovrasti, 2015).

Data Collection and Validation:

- Data collection and validation is essential but also by far the costliest part of establishing a road asset GIS (Vanier, 2004). Vanier (2004) presents the high cost of collecting and validating spatial data as one of the primary barriers for road asset management. With surveys often being field based and wide speared, costs escalate (Vanier, 2004).
- Advances in Internet of Things (IoT) technology and remote sensing coupled with AI analysis can reduce data collection costs while improving data update frequency (Song & Wu, 2021). However, in GIS the output quality is largely dependent on the quality of the input data, which if obtained from various sources of differing and inconsistent quality, will limit accuracy and applicability for analysis (Alhamwi, et al., 2021).

Technical Expertise:

- Effective use of GIS necessitates context capacity. There is a need for training and capacity-building among practitioners to fully leverage streetlighting data in GIS analysis - to implement decisions and perform functions in an effective, efficient and sustainable manner (Samarakoon, et al., 2008). The widespread integration of GIS has seen users changing from professionals to non-specialists, which brings new challenges to GIS, necessitating that next-generation GIS systems are easy to use. Professionals establishing systems need to promote easy geo-computation to more domains and to more people (Song & Wu, 2021).

Software and Tool Limitations:

- Alhamwi (2021)'s custom tool for simulating electricity demand and renewable energy integration in streetlighting, serves as an example of how a custom tool can be a constraint. The Tool does not account for physical parameters such as the height and spacing of streetlight poles or the type of lighting technology used. Yet these factors can influence energy consumption, resulting in further development of the model required, to offer a comprehensive simulation (Alhamwi, et al., 2021). While the GIS does present great advances in infrastructure management, as with any software there are limitations and as such it is key to establish standards, formats and tools that speak to not only the application and integration requirements currently but to design and implement solutions with robustness for the future.

2.2.3.3 Implementation in Organisational Environments

Masser & Ottens (2019) draws attention to the challenges of implementing multi-user GIS systems in complex organisational environments, such as local governments or public infrastructure agencies. They critique the technological determinist and managerial rationalist approaches that assume technology adoption will automatically lead to positive outcomes. Instead, they advocate for a social interactionist approach, where it is assumed the success of GIS implementation depends on the interaction between the technology and its users within the organisation's specific view of the technology. This agreement holds true in the context of the WCG, where in the past there has been resistance to adoption of new system wide technologies, as ill guided management has forced ineffective technologies for the sake of progress.

For the GIS-based capturing and analysis of roadway lighting assets, this insight is particularly valuable. Successful implementation of a GIS for streetlighting would depend not only on the technical capabilities of the system but also on the alignment of organisational structures, user needs, and management processes. Effective information management structures, participation from all organisational levels, and an ability to cope with change are critical for the long-term success of an enterprise GIS (Masser & Ottens, 2019).

2.2.4 Future Directions

Since its inception in the 1960s, GIS has played an important role in improving information technology which in turn promotes the progress of GIS. Song & Wu (2021) suggests that advancements in big data, artificial intelligence (AI), IoT, mobile computing, and cloud computing are influencing and transforming GIS (Song & Wu, 2021). These revolutionary technologies provide new opportunities for GIS and what can be achieved with or derived from spatial data.

In roadway lighting, this could translate into GIS-powered dashboards that monitor the condition of streetlights in real-time, alerting managers to failures and facilitate proactive maintenance (Xhafa & Kosovrasti, 2015). Xhafar & Kosovrasti (2015) validates the implementation of GIS in monitoring and managing urban infrastructure, providing examples of how integrated analysis can support sustainable planning.

2.2.4.1 Improved Data Collection Methods

The WCG requirements for field validation of asset locations can be achieved by using smart handheld GPS devices that offer customisable tools for field data collection (Wollaston, et al., 2016). Usage of smart phones with applications such as ArcGIS Field Maps or QField allow for data capture on inexpensive real time connected devices that can share data directly to a GIS database (Nowak, et al., 2020).

However, the collection of data is not only limited to the initial capture, multi-source data acquisition and integration, as well as the ability to handle geospatially structured, semi-structured, and unstructured data, is crucial for effective asset capture and management in the long run (Song & Wu, 2021). Advancements in data collection methods, including the use of drones and other high-resolution remote sensing technologies, could improve the accuracy, collection time, and temporal frequency of streetlighting data. A GIS environment can integrate data from various sensors, IoT devices and remote sensing that could enhance the precision and comprehensiveness of streetlighting along the network (Alhamwi, et al., 2021) (Nowak, et al., 2020).

GIS offers the ability to process and analyse large volumes of data efficiently through cloud distributed computing and the scalability of large data storage (Song & Wu, 2021). Alhamwi (2021)'s case study in Berlin documents a practical example of how streetlight infrastructures can be mapped and analysed from open-source data using GIS, proving it is an effective tool for collection and simulation of streetlights (Alhamwi, et al., 2021).

2.2.4.2 Sustainability and Environmental Impact

There is a growing need to incorporate sustainability metrics into roadway lighting analysis. By leveraging a GIS based asset inventory to introduce location, electricity consumption, installation type, status, etc. allows for the modelling of energy efficiency and environmental effects of larger areas in less time (Rabaza, et al., 2018). Geo AI as described by Song & Wu (2021), focuses on spatiotemporal big data analysis through artificial intelligence, to support optimal decision making in an automated fashion by means of data-driven, self-learning technology. Geo AI is particularly applicable in urban infrastructure planning and optimisation, and by extension roadway lighting. Geo AI could plausibly be used in optimising the placement and operation of lighting assets using AI-driven analysis leading to reduced energy consumption, lower operational costs, and minimized environmental impact (Song & Wu, 2021).

Studies focusing on sustainability shows GIS leveraged to evaluate the environmental impact of different lighting technologies. With the integration of GIS modelling and appropriate assessment, energy performance can be improved, and environmental impacts reduced (Tomczuk, et al., 2021). GIS can also serve as a tool to assess environmental externalities of street lighting as demonstrated by the analysis conducted by (Boulanger, 2017) in terms of the impact of light pollution on the natural night sky and effects on human health and the environment.

2.2.4.3 *Automation and Intelligence*

Literature presents several advanced implementations of GIS that could be applied to roadway lighting. Vanier (2004) discusses the integration of GIS with ‘expert systems’ to manage municipal infrastructure. In the case of street lighting, such integrations could automate fault detection, such as identifying lights that need repair based on spatial data and automate work order generation (Vanier, 2004). Additionally, Vanier (2004) points to the use of GIS in predicting ice buildup on roads and managing irrigation usage in water zones, suggesting that similar predictive capabilities could be developed for street lighting systems.

Future technology such as Geo AI, with its focus on self-learning systems and automated decision-making processes, is pertinent to management support, as it can integrate new data sources (and real time data) with traditional models (Song & Wu, 2021). Feasibly GIS could be employed to predict areas requiring increased lighting based on traffic patterns and safety concerns – derived from a multitude of real-time data inputs.

2.2.5 Case Study Review of GIS Mapping of Roadway Lighting

The paper "Geographic Information System Mapping of Roadway Lighting and Traffic Accidents" by (Saraiji, et al., 2009) provides an exploration of how GIS technology can be utilised for the modelling, analysis, and planning of roadway lighting infrastructure. The study demonstrates a GIS-based approach to evaluate the effectiveness of existing streetlighting and its impact on traffic safety, particularly in terms of nighttime accidents.

Saraiji, et al., (2009) outlines the creation of a GIS spatial database, which includes for over 52,000 streetlight fixtures and their attributes. They use this data to model the lighting coverage on roadways by assigning an effective illumination area around each streetlight. The GIS environment overlays these illumination areas onto street maps, enabling a visual assessment of lighting conditions across the network. This lighting model communicates the state of streetlighting infrastructure and forms the foundation for analysis and planning.

To analyse the lighting infrastructure along the network, the study calculates the percentage of each street segment that is adequately illuminated and compares this with traffic accident data. This spatial analysis is extended to intersections, where the study evaluates the relationship between the number of streetlights and the ratio of nighttime to daytime traffic accidents.

The findings emphasize the importance of adequate lighting infrastructure, revealing that a significant number of intersections with high nighttime accident rates have insufficient lighting as per IES recommendations. Specifically, intersections with a nighttime / daytime accident ratio greater than 1.00 often had fewer than four streetlight poles, indicating that inadequate lighting may contribute to higher accident rates (Saraiji, et al., 2009).

Saraiji, et al., (2009) concludes by highlighting the utility of GIS in the planning and improvement of lighting infrastructure. By identifying poorly lit areas and their correlation with traffic accidents, GIS serves as a powerful tool for decision-makers. It aids in the strategic planning and allocation of resources to enhance roadway lighting, thereby potentially improving traffic safety and reducing nighttime accidents (Saraiji, et al., 2009).

This work underscores the critical role of GIS in the modelling and analysis of lighting infrastructure, offering a methodological approach to practically evaluate streetlighting design at a local level.

Saraiji, et al., (2009) finds current GIS tools offer analysis functionality far beyond what the statistical package "R" employs. GIS analysis that can be conducted on streetlight data includes (Mitchell, 1999):

- Spatial Statistics Tools (Hot Spot Analysis, Spatial Autocorrelation and Cluster and Outlier Analysis) Interpolation and Surface Analysis (Kernel Density Estimation, Empirical Bayesian Kriging)
- Proximity Tools (Buffer and Near Analysis)
- Pattern Analysis (Ripley's K Function and Multi-Distance Spatial Cluster Analysis)

Tools that leverage external data or attributes that drive strategic planning include (Mitchell, 1999):

- Network Analysis (Service Area Analysis and Closest Facility)
- Data Enrichment (Adds additional demographic, environmental data or relations to other road features) and
- Statistical Analysis (statistical models, including regression and kriging, for analysing the relationship between streetlight placement and other factors such as accident rates or crime statistics), and even Space-Time Pattern Mining (Emerging Hot Spot Analysis)

2.2.6 Summary and Conclusion

Literature shows GIS mapping and analysis are valuable tools in a road asset management system for enhancing road safety, optimising energy use, and managing costs. Literature notes challenges related to data accuracy, integration, and technological constraints that must be considered, but concedes that GIS is an established and feasible solution. Recent research on integrating smart technologies and improving data collection methods have greatly advanced the field and demonstrate the critical need for the WCG to establish a data foundation, in terms of a spatial data respiratory, to leverage these technologies and practises.

Literature generally supports the notion that streetlighting is crucial for road safety and reports the growing global demand for streetlighting and its environmental and financial impacts, highlighting the necessity for sustainable solutions (Alhamwi, et al., 2021). As such streetlighting can be framed as both a critical public good, yet also a challenge, due to its costs, environmental impacts, and inefficiencies in deployment (Murray & Feng, 2016).

Geographic Information Systems have become a key tool in urban planning and infrastructure management, including roadway lighting. GIS concepts underlying the GIS systems of today have been in existence for over 30 years, however, it is only computing advancements over the last decade that have made it possible to widely exploit the opportunities of GIS (Masser & Ottens, 2019) (Xhafa & Kosovrasti, 2015). Literature maintains by leveraging GIS, urban planners and infrastructure managers can effectively map, analyse, and optimise streetlighting infrastructure (Xhafa & Kosovrasti, 2015).

2.2.6.1 GIS Advocacy

Xhafar's paper presents GIS as an indispensable tool in urban planning, offering substantial benefits in spatial analysis, data management, and decision-making processes. The applications discussed, such as infrastructure monitoring and land-use planning, are highly relevant to roadway lighting analysis. Their work suggests GIS will provide a robust framework for capturing, mapping, and analysing roadway lighting assets, enabling authorities to optimise public lighting systems. While noting challenges, many may be mitigated by the ongoing advancements in GIS technologies.

2.2.6.2 Application of GIS and Spatial Data

Vanier (2004) endorses the versatility of GIS in managing municipal infrastructure, including its potential for roadway lighting analysis. The benefits of integrating GIS in this context are clear: enhanced decision-making, improved asset tracking, and optimised maintenance strategies. However, the challenges of data collection costs, system integration, and limitations in 3D modelling highlight areas for further research and development. The paper suggests that future advancements in GIS could greatly enhance its effectiveness for managing complex infrastructure assets like roadway lighting (being both individual and part of a greater network), provided these challenges are addressed. Emphasise is placed on the need for continuous innovation in data integration and system capabilities.

Lemer (1998) focuses on integrated infrastructure-asset management (IIMS), presenting a comprehensive framework for managing public infrastructure assets to maximise public profit. The paper articulates that an efficient asset management approach is necessary to ensure the proper deployment of public capital, addressing the challenges associated with the complexity of public assets, including diverse infrastructure systems such as roads, sewers, and utilities. GIS as part of an IIMS framework allows for enhanced data collection, asset tracking, performance modelling, and decision analysis, all of which are critical for the efficient management of roadway lighting assets. Lemer suggests the full potential of GIS can only be realised when combined with complementary technologies and integrated management tools, such as advanced financial and optimisation systems. While the paper is dated, and solutions in terms of several integration and optimisation problems already exist, the broad scope and underlying principles of asset management outlined are still relevant to the capture, mapping, and analysis of roadway assets in terms of GIS.

Alhamwi (2021) underscores the growing importance of GIS in urban asset management, particularly in the context of roadway lighting. They present evidence of a GIS tool providing a solution for city planners to model and analyse streetlight infrastructure while considering the integration of renewable energy. While noting the challenges related to open-source data quality and implementation costs, the paper provides a proven example using GIS for promoting sustainability in urban streetlight systems.

Murray & Feng (2016)'s work emphasises the role of GIS in asset management and illustrates how efficiency and sustainability of public lighting systems can be evaluated using GIS. They address the key problem of streetlight placement in real-world continuous spaces, by deriving a GIS model that informs spatial optimisation in a continuous space - providing an actionable solution. This application of GIS offers valuable insights into how a systematic reassessment of streetlight placements can enhance network management and growth, while promoting efficiency. As GIS technology evolves, the potential to integrate even more sophisticated models and real-time data into roadway asset analysis and management will continue to grow, making it a critical tool for advancing public infrastructure systems (Murray & Feng, 2016).

2.2.6.3 GIS Implementation

Masser & Ottens (2019) offers the distinction between the static, task-oriented GIS applications of the plan-making tradition and the dynamic, multi-user systems of the administrative tradition – and highlight the importance of designing GIS solutions that are adaptable to both short-term projects and long-term asset management. Furthermore, the emphasis on organisational context and user interaction underscores the need for careful planning and management in the implementation of GIS technology, particularly in public infrastructure contexts.

2.2.6.4 Innovation Through GIS

Song & Wu (2021) offers insights into the future direction of GIS in the new IT era, which are highly relevant to innovation in streetlighting management. The study demonstrates how capturing streetlighting data and establishing a record in a GIS environment forms the foundation for leveraging automation and intelligence, which can advance the efficiency and effectiveness of infrastructure projects (Song & Wu, 2021). Song &Wu's discussions on improved data collection and analysis using GEO AI offer the potential for automated, informed, sustainable infrastructure planning and management.

3. DEVELOPING THE MOBILE STREETLIGHT CAPTURE REQUIREMENTS

3.1 Mobile Device Suitability

The fundamental field data capture kit consists of a handheld device which is compatible with mobile mapping software and equipped with Global Navigation Satellite System (GNSS) receiver. Current mobile computing power and software are generally aligned to function which leaves GNSS as the main variable to consider. GNSS refers to the determination of location based on satellite transmitted data. Various satellite constellations (Galileo EU, GPS USA, GLONASS Russia, BeiDou China) provide signals from Earth orbits, containing positioning and timing data, to dedicated receivers that allow for position calculation (Langley, et al., 2017).

3.1.1 Global Navigation Satellite System Requirements

Currently there are no dictated satellite constellations covering South Africa, but the area is adequately covered by the growing number of international GNSS constellations, as such the availability or visibility of satellites does not present a challenge (Nowak, et al., 2020). Modern receivers are also capable of combining data from various GNSS systems to provide uninterrupted location data and improve accuracy (ESA, 2011).

The accuracy of a GNSS receiver can range from serval millimetres (survey grade GPS) to several meters (mapping GPS) depending on the instrument construction (receiver capability antenna type, shielding, processing) and location (under cover or obscured and multipath signal interference) (Chivers, 2003) (ESA, 2011) (Nowak, et al., 2020). Processing of data also directly affects accuracy, as the passage of satellite signals though the atmosphere degrades their quality leading to inaccuracy in the location, and along with other errors, can only be corrected (and accuracy improved) through processing (Langley, et al., 2017) (Nowak, et al., 2020). By utilising differential global positioning system (DGPS) to derive corrections, inherently required due to degraded data signals, accuracy can be improved.

These DGPS systems require two receivers and a 'known point' and can be implemented through Real Time Kinematic (RTK) correction or post processing (Darrozes, et al., 2016). In the absence of a known point a Local Area Augmentation System (LBAS) or a Virtual Reference Station (VRS) can provide a fixed 'known point'. Both LBAS and VRS are provided by a network of continuously operating GNSS base stations in South Africa known as TrigNet, which communicates to GNSS receivers over the internet (NGI, 2021). While the equipment that makes use of these systems is traditional expensive, cumbersome (consisting of an external antenna) and limited to the survey grade GPS, there is a trend towards implementing this at a lower cost in aerial drone navigational equipment. Satellite-based Augmentation Systems (SBAS) fulfil a similar role to LBAS but at a regional area and by communicating corrections via geostationary satellites (EUSPA, 2024).

GNSS technology is constantly improving a satellite coverage growing, allowing for accuracy improvements through sheer volume of observations and more intelligent interpretation of by powerful software-based receivers. The consumer-grade GPS found in smart phones and tablets offers an accuracy of 2-5m and mapping-grade GPS's have an accuracy up to 1m (Nowak, et al., 2020). The WC Roads RNIS currently maintains an accuracy of 25m or less which falls well within the capabilities of consumer devices.

3.1.2 Mobile Device Selection

The GNSS market is dominated by smartphones, accounting for approximately 5.4 billion of the 6 billion consumer devices with GNSS chips in circulation in 2019 (Nowak, et al., 2020). Most smartphone manufacturers have moved away from dedicated OS's, standardising to either Android or iOS (Nielson, 2013). This standardisation has facilitated a broad array of both free and enterprise-based field mapping applications that are both multi-platform and multi-device compatible. Smartphones are the most practical choice for this study, considering several context-specific factors:

- The methods described should be device-independent, enabling the software to accommodate technological advancements and changes without requiring redevelopment.
- General asset capture of streetlights will not subject devices to harsh environment necessitating a need for a specifically ruggedized device (Nielson, 2013).
- Smartphones are not specialised, easy to replace, and do not require dedicated limited-service centres, leading to down time.
- Smartphones are low-cost when compared to dedicated GNSS mapping devices, leading to lower capital requirements (Nielson, 2013).
- The competitive smartphone market maintains continuous technological advancement while maintaining reasonable cost to value.
- Smartphones meet the software and GNSS requirements, while offering customisation and various other uses.
- The primary motivation is that most WCG Roads Directorate employees already carry a smartphone during their travels, and the department has established effective processes for acquiring and managing smartphone contracts.
- Most user are already familiar with use of their smartphone, resulting in a limited amount of training required.

During the initial phase, the use of dedicated mapping devices was considered; however, their widespread deployment for similar future projects, along with associated training requirements, was deemed cost prohibitive. Early tests demonstrated that smartphones, equipped with protective covers and supported by vehicle chargers or external power banks for all-day use, provided a practical alternative. Consequently, the study selected a non-specific smartphone as the mobile capture tool.

3.2 Identification of Data Capture Application

GIS tools used for infield data acquisition have become widespread in recent years, with most GNSS-equipped smart phones and tablets presenting a viable platform for numerous GIS themed mobile applications (Nowak, et al., 2020). Selecting the application, as discussed in literature, should be based not only on the functionality of the application, but its environmental support (development and maintenance) and integration (amalgamation with existing systems and data) in the GIS domain, both universally and organisation specific. When selecting an application, a complementary system is desired, which not only allows the collection of geographical position data of streetlights and their attributes, but integrates with the existing WCG Road's GIS environment which allows further storage, processing and presentation in situ (Nowak, et al., 2020).

The WCG Roads Directorate makes use of the Esri suite of GIS software. As such the Esri Field Maps application would be the most suitable mobile data capture application, as it is fundamentally aligned and integrated with the Esri software used by the greater WCG GIS environment and WCG GIS systems. This decision is further substantiated by literature showing that Esri software and environment is well suited to assets and spatial data analysis related to roads, as implemented in several studies (Moscovivi, et al., 2022) (Alkhadour, et al., 2021) (Nielson, 2013).

4. CREATING A ESRI FIELD MAPS APPLICATION

This section outlines the setup of an ArcGIS Online Field Maps application, specifically designed to facilitate the collection of streetlight pole data along the WCG road network. The objective is to create an intuitive and efficient tool that enables field workers to gather precise, geolocated data on streetlight assets. This data will contribute to building a centralised and up-to-date streetlight repository to inform infrastructure management processes.

Use of the ArcGIS Field Maps application offers several critical advantages for managing streetlight assets: It allows field personnel to capture high-quality location and attribute data directly through mobile devices, even in offline conditions. By integrating this tool into the asset management workflow, the WCG can ensure the availability of current and accurate data to support analysis, planning, and decision-making for roadway lighting infrastructure. This solution aligns with the WCG's broader infrastructure objectives by providing reliable data for maintenance planning, budget allocation, and energy efficiency initiatives across the streetlight network.

The following sections demonstrate the configuration process of ArcGIS Field Maps application within ArcGIS Online. While not exhaustive, key aspects are considered that address:

- Creating the Data Schema: Designing a structure to capture essential streetlight attributes.
- Designing a User-Friendly Interface: Developing a clear and practical layout for field data collection.
- Ensuring Data Integration: Setting up workflows for seamless integration into the broader data management system.

By detailing these steps, this section serves as a guide for GIS professionals and field technicians in building effective data collection workflows that enhance the accuracy and accessibility to infrastructure asset data.

The WCG Roads Directorate has some key requirements which define aspects of the envisaged ArcGIS Field Maps applications that include:

- Live data sync with data bases, enabling real time updates.
- Controlled access: A trusted, small group of users with editing privileges.
- Device independence: Compatibility across various devices for flexible deployment.
- GPS accuracy: Location data with a precision of 3.5 meters.

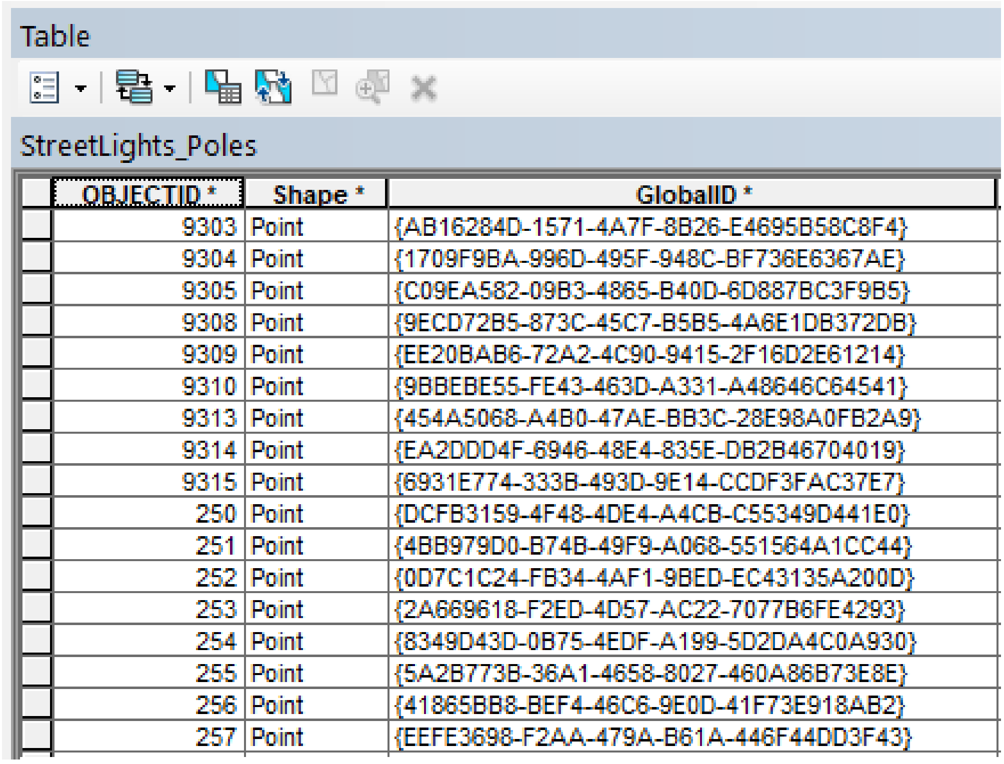
4.1 Esri Environments and Database Infrastructure

In the context of the WCG Roads Esri Environment, ArcGIS Field Maps is not capable of functioning as a live (synchronised) dataset in the Roads' local ArcGIS Server and Portal due to the limitations applied by the WCG domain security. This security blocks external access via the internet and the internet protocols used by fields maps to transfer data and communicate with WCG Roads ArcGIS environment. To overcome this the relevant data sets are housed in the WCG organisational ArcGIS Online environment. The WCG system administrator established a data tunnel between the WCG ArcGIS Online and WCG Roads Environments.

Spatial data can be collected and saved in various formats. ArcGIS Online natively offers several formats, including shapefile, CSV, Excel, and KML for download (Rossiter, 2022). These universal formats offer compatibility but lack the ability for advanced spatial analysis and native integration into the existing WCG Roads GIS environment and workflows (as per the internal standards). While the Esri suite works with various Esri derived data formats such as shapefiles and layer-packages (and non-Esri products such as AutoCAD, KML, etc.), the geodatabase is the built-in data structure for Esri GIS products and is the primary data format used for editing, data management and analysis (Bajjali, 2018). A geodatabase facilitates the storage of various types of data, including vector, raster, and tabular data, supporting ArcGIS Pro's advanced analysis functionality (Bajjali, 2023).

Geodatabases can take various forms with the folder-based system being the most common, yet in the application of the WCG Roads Esri environment a Spatial Database Engine (SDE) is employed. A SDE allows a database management system (DBMS) to be extend with spatial technology (ESRI, 2000). Implementation of SDE offers all the benefits associated with DBMS's, in terms of data management, integrity, redundancy, accessibility and security. While effectively offering an interface that integrates with Esri products in the same way as a geodatabase, by housing primary dataset types such as tables and feature classes (not well suited for raster datasets). The WCG Roads GIS environment has several SDE geodatabases with a specific one dedicated to data that interacts with the WCG ArcGIS Online platform. This SDE geodatabase has been selected to contain the streetlight data due to the requirement of the specific deployment of Field Maps to work via WCG ArcGIS Online. The primary dataset of relevance to streetlight capture is the Esri feature class. Feature classes are contained in the geodatabase, either standalone or grouped under feature datasets, and can be of point, line, polygon or poly-line type, depending on the type of data features it contains.

Streetlight locations captured in the field, by means of ArcGIS Field Maps, are collected as individual feature points and their attributes, in a single feature class. The point feature class "StreetLights_Poles" was created as part of the study, to collect street light points, with no attributes other than the spatial location and unique identifiers, with the intention of transferring in postprocessing the associated attributes based on the proximal road attributes. Figure 1 shows the 'StreetLights_Poles' attribute table containing only automatic unique identifiers as attributes.



Table

StreetLights_Poles

OBJECTID *	Shape *	GlobalID *
9303	Point	{AB16284D-1571-4A7F-8B26-E4695B58C8F4}
9304	Point	{1709F9BA-996D-495F-948C-BF736E6367AE}
9305	Point	{C09EA582-09B3-4865-B40D-6D887BC3F9B5}
9308	Point	{9ECD72B5-873C-45C7-B5B5-4A6E1DB372DB}
9309	Point	{EE20BAB6-72A2-4C90-9415-2F16D2E61214}
9310	Point	{9BBEBE55-FE43-463D-A331-A48646C64541}
9313	Point	{454A5068-A4B0-47AE-BB3C-28E98A0FB2A9}
9314	Point	{EA2DDD4F-6946-48E4-835E-DB2B46704019}
9315	Point	{6931E774-333B-493D-9E14-CCDF3FAC37E7}
250	Point	{DCFB3159-4F48-4DE4-A4CB-C55349D441E0}
251	Point	{4BB979D0-B74B-49F9-A068-551564A1CC44}
252	Point	{0D7C1C24-FB34-4AF1-9BED-EC43135A200D}
253	Point	{2A669618-F2ED-4D57-AC22-7077B6FE4293}
254	Point	{8349D43D-0B75-4EDF-A199-5D2DA4C0A930}
255	Point	{5A2B773B-36A1-4658-8027-460A86B73E8E}
256	Point	{41865BB8-BEF4-46C6-9E0D-41F73E918AB2}
257	Point	{EEFE3698-F2AA-479A-B61A-446F44DD3F43}

Figure 1: Attribute table of field capture feature class "StreetLights_Poles"

4.2 Feature Class and Feature Service

The feature class, used to collect the streetlight point features, requires certain default settings changed under its management properties, which allows the data to be edited in ArcGIS Field Maps both while internet connection is available and while offline (in areas where cellular coverage is not available). These settings include enabling versioning in the geodatabase and enabling attachments to allow images to be captured in field and attached to points. While images of assets are not required it is deemed a good capability to have to communicated field conditions/situations to office staff for further investigation or evaluation if required. Figure 2 shows these settings in the feature class properties.

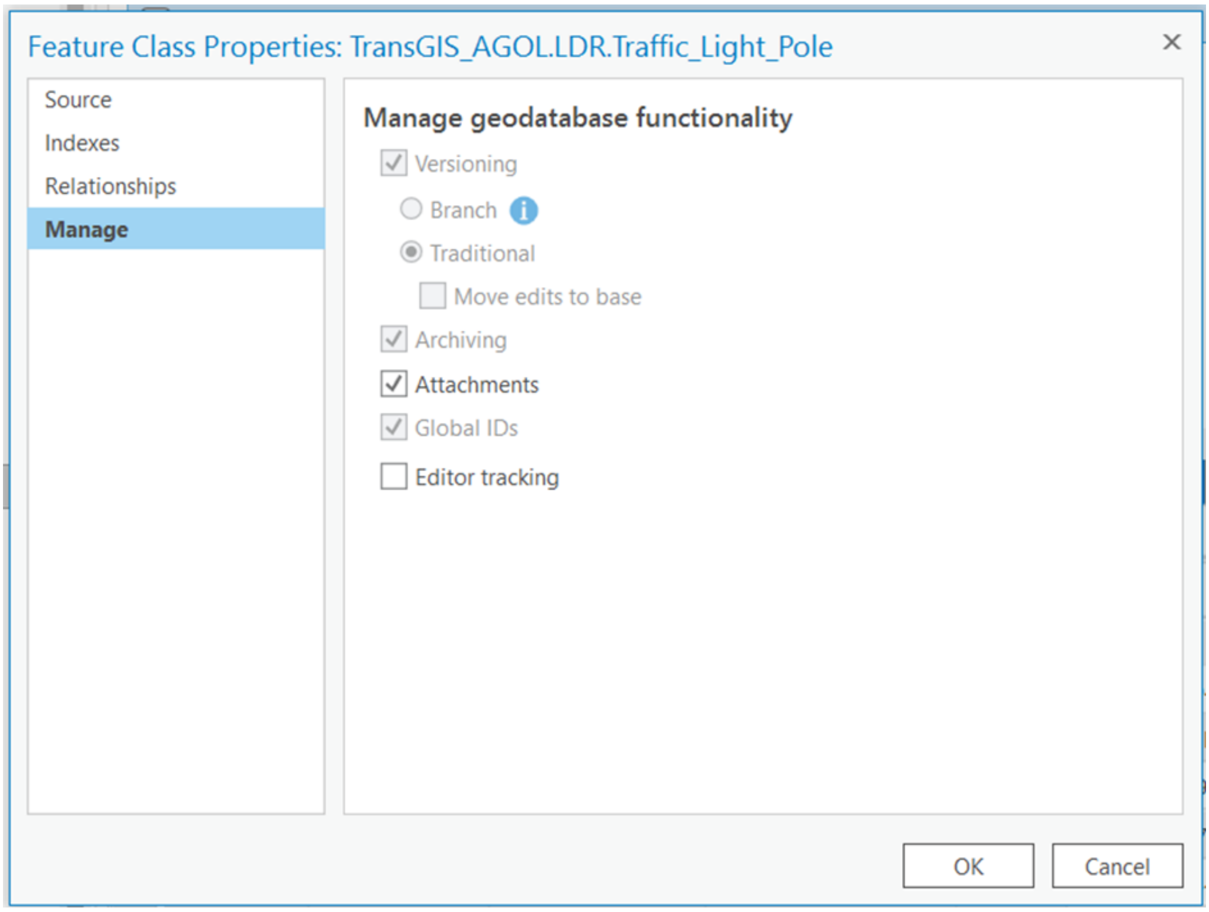


Figure 2: Field capture feature class settings for traffic lights

For the feature class to be consumed within ArcGIS Field Maps and the WCG Roads GIS Portal it must be published to the WCG Roads ArcGIS Server as a feature service. The feature service serves feature data and nonspatial tables (attachments) over the internet or intranet, allowing the data to be used in web clients, desktop applications, and field applications (Esri, 2024). The feature service is based on the data contained in the feature class it is referencing and the symbology applied to it at the time of publishing. Publishing and symbology assignment are completed in ArcPro desktop software, this also establishes a symbology template used for any features added to the feature class in Field Maps. Figure 3 shows the feature class being symbolised in ArcPro.

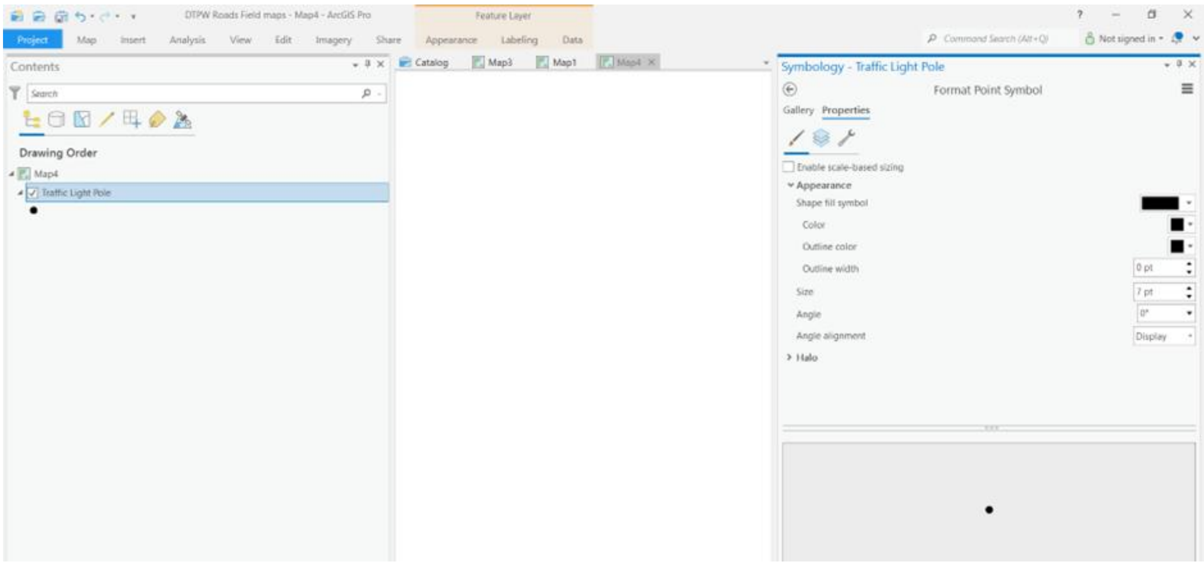


Figure 3: Establishing a symbology template for Arc Field Map feature layers in ArcPro

Publishing the feature service is achieved via the ‘share’ functionality in ArcPro with the following fields required in the publisher as indicated in figure 4. Crucially the data needs to be referenced to the SDE where the original feature class resides and not copied to the server itself, this allows database users access to the features captured by ArcGIS Field Maps.

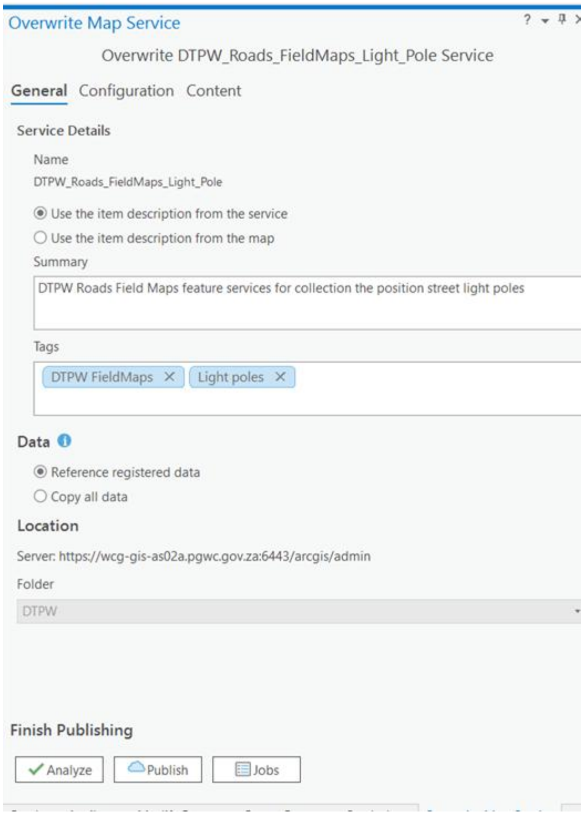


Figure 4: Publishing the field capture feature service in ArcPro.

The feature service, like the feature class, requires configuration to enable editability, synchronisation and export. Figure 5 indicates the required settings under the configuration menu of the feature service publisher.

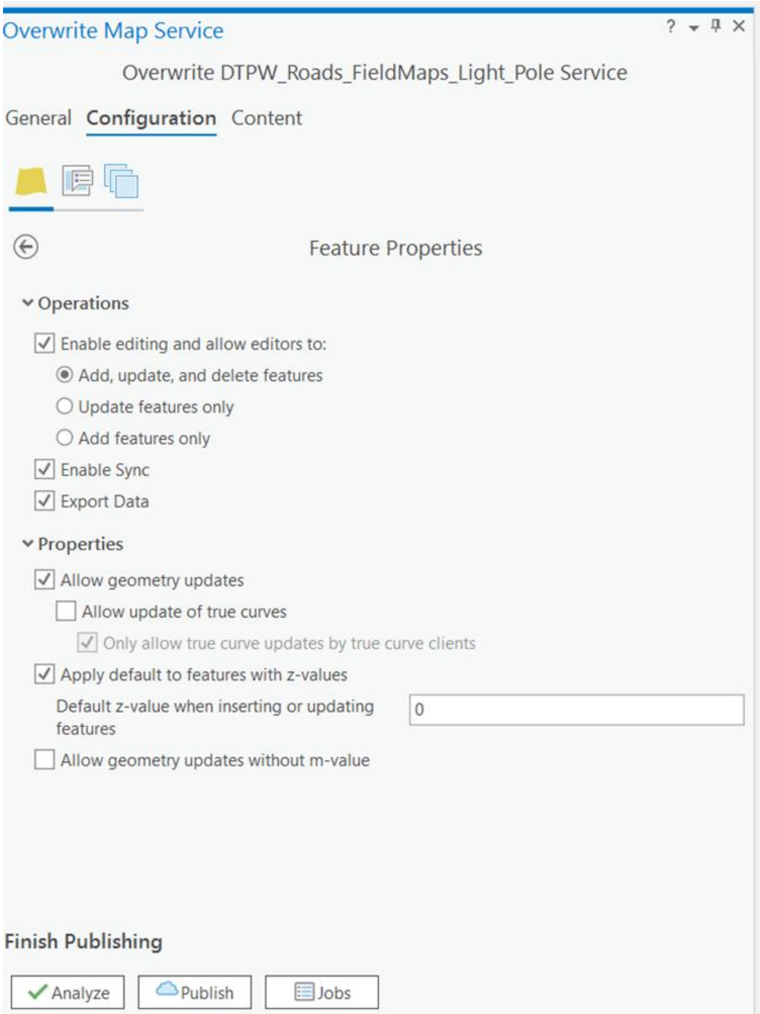


Figure 5: Allowing editability and synchronisation of the feature service

Once the feature service is published to the server, the necessary security setting can be updated to grant Field Maps users edit and access rights. Figure 6 indicates the rights being allocated using ArcGIS Server Manager. This addresses the WCG requirement for access control, which is critical in a live system.

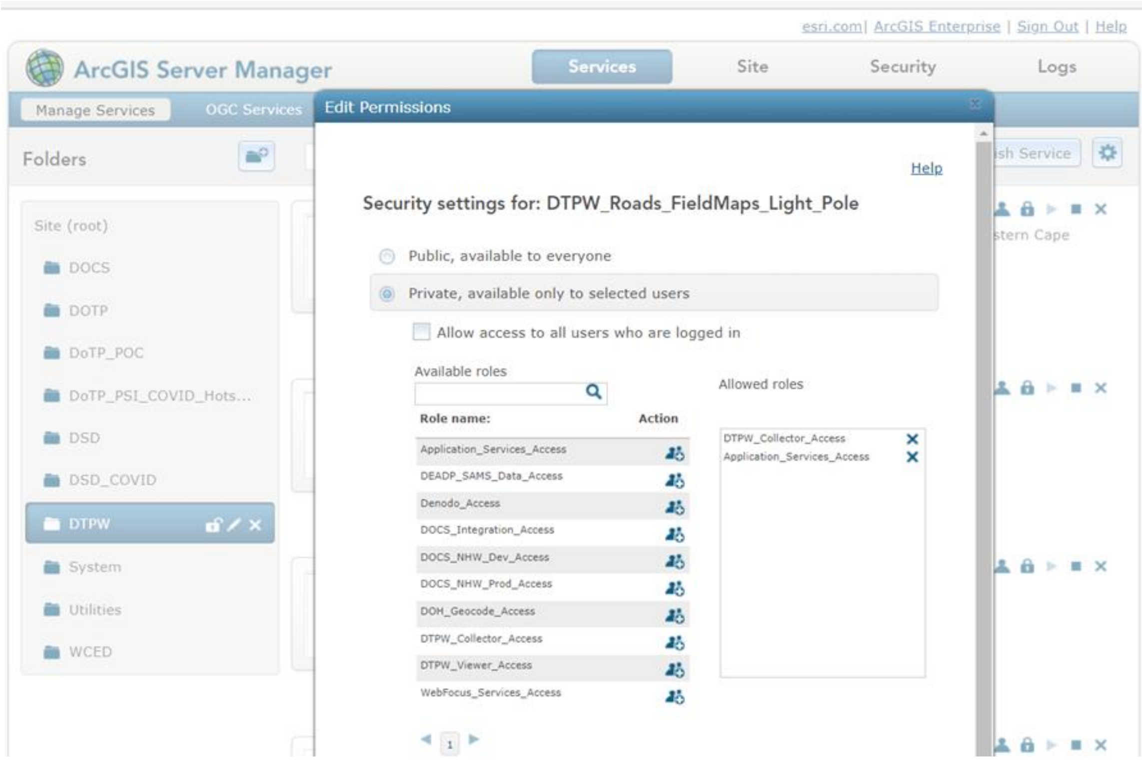


Figure 6: Allocation of access to specific users

Importing the secured feature service into ArcGIS Online completes the preparation of the feature class for integration within the GIS environment, including compatibility with ArcGIS Field Maps. Once published, the feature service becomes a URL-accessible resource. It is then shared with ArcGIS Online by providing the URL path along with the associated username and password for the secured feature service.

4.3 Configuring the ArcGIS Online Map

To allow ArcGIS Field Maps to capture data in a feature class, it must be given access via a map that is created in ArcGIS Online from the published feature service. This involves adding the feature service to a new web map template in the organizational account in ArcGIS Online, which provides the content to ArcGIS Field Maps. While the web map allows adjustments to be made to the feature symbology, any changes will not translate to Field

Maps. When adding a new feature in Field Maps the symbology of the feature class will default to that with which the feature service was published, adjustments cannot be made in ArcGIS Online. The map will allow configuration of pop-ups to display relevant field attributes and enable labels for information where required. Further any other base data or reference data can be added to enrich the map for in-field orientation and reference. Figure 7 shows the new web map with the addition of the feature service renamed as Street Light Poles.

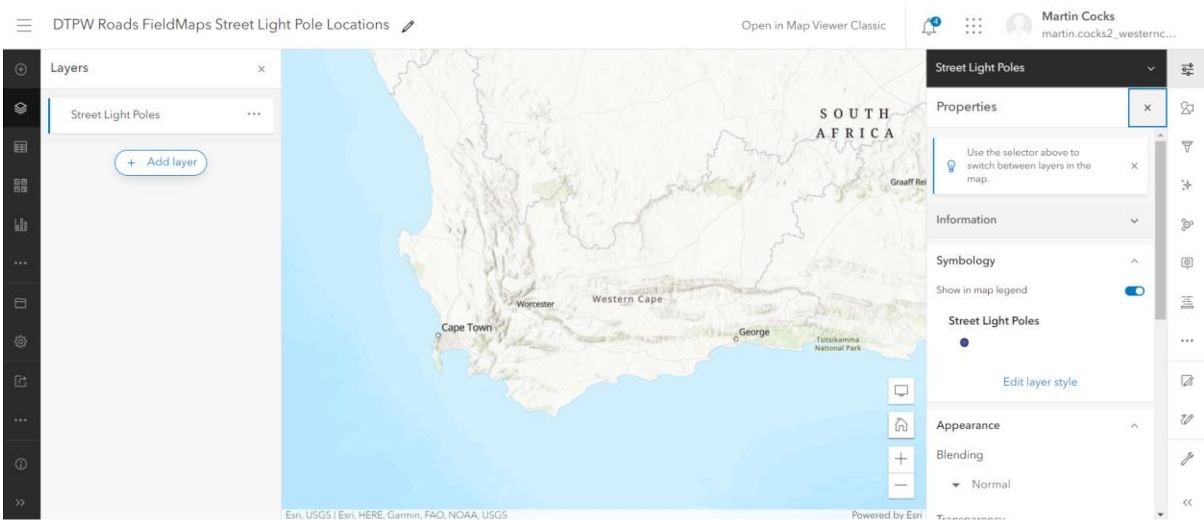


Figure 7:Web map preparation for Arc Field Maps

Configuring the developed map for use in Field Maps requires simply selecting the Map within the ArcGIS Field Maps Application in ArcGIS Online. Figure 8 shows the Map selection and Figure 9 indicate the map properties in the ArcGIS Field Maps Application.

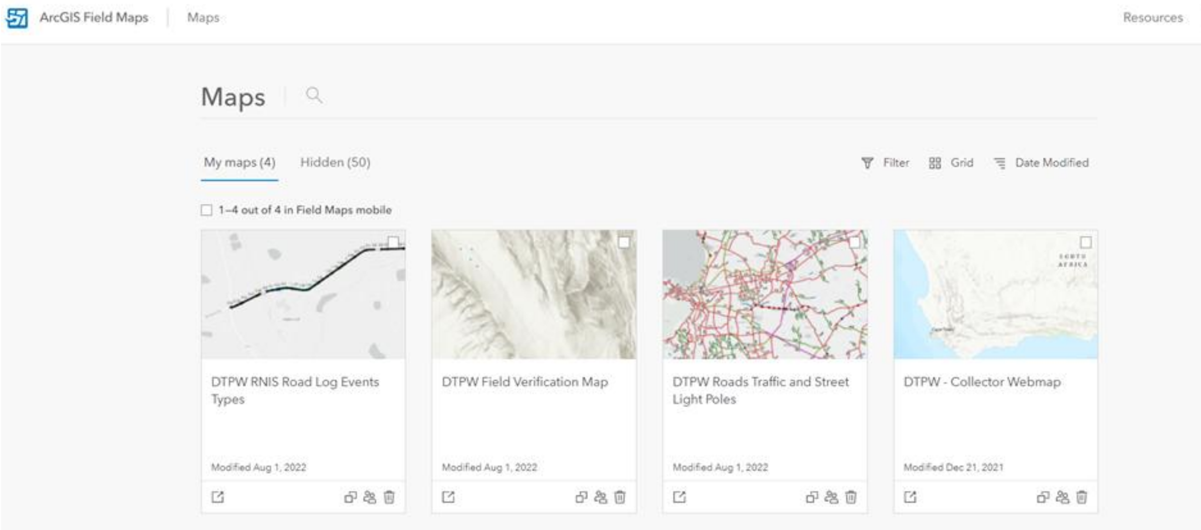


Figure 8: ArcGIS Field Maps map selection

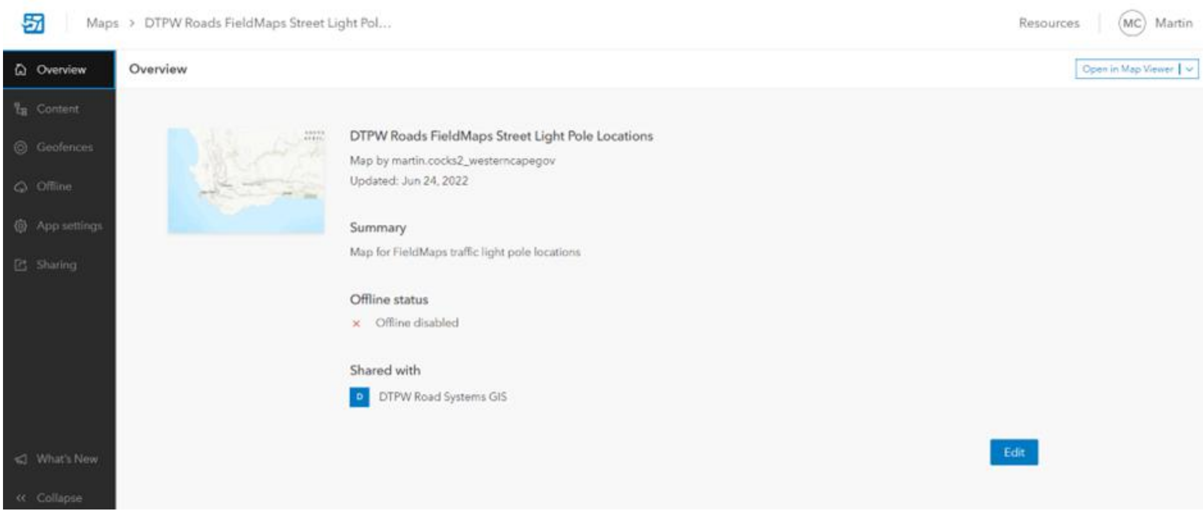


Figure 9: ArcGIS Field Maps map properties

4.4 Configuring the ArcGIS Field Maps Application in ArcGIS Online

Setting up ArcGIS Field Maps for field data collection requires configuration in three key areas: the application form, application settings, and application sharing (security). These configurations ensure the application is ready for simplified, uniform and accurate data collection on mobile devices.

4.4.1 Configuring the Application Form:

- The ‘Content’ menu in ArcGIS Online allows adjustment of editable feature classes used in data collection. Here forms are set up for adding or editing points in the field, such as entering or updating a Streetlight Pole ID.
- Form templates offer structured data entry options for feature layers. Templates define default values and field options to make data collection faster and reduce errors. In this instance, because the feature service was previously published, the template will be based on those settings, guiding users capturing streetlight pole data in a consistent manner. Figure 10 shows the form creation menu in ArcGIS Field Maps.

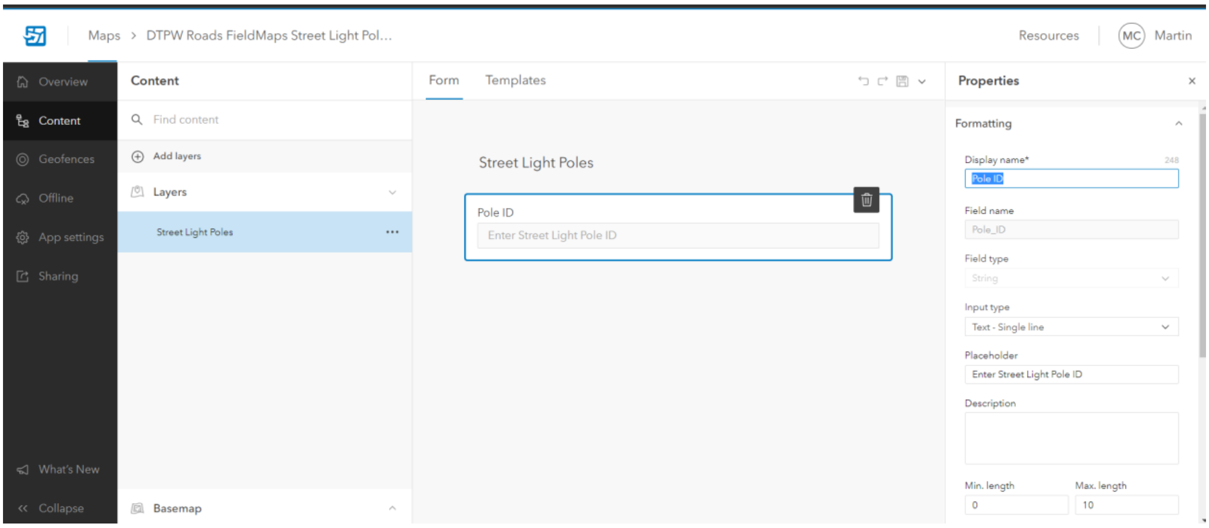


Figure 10: Form menu in ArGIS Field Maps

4.4.2 Configuring Application Settings:

The application settings menu allows customisation of ArcGIS Field Maps functionality on portable devices. These settings include offline mode, basemap preferences, and GPS accuracy thresholds that are adjusted to optimise data collection under various field conditions. These settings ensure data integrity yet allow a certain degree of adaptability based on field conditions i.e. If lower accuracy is allowed but observations (epoch) are increased. Figure 11 shows the various categories of settings, with generic values normally proving sufficient for functional application development.

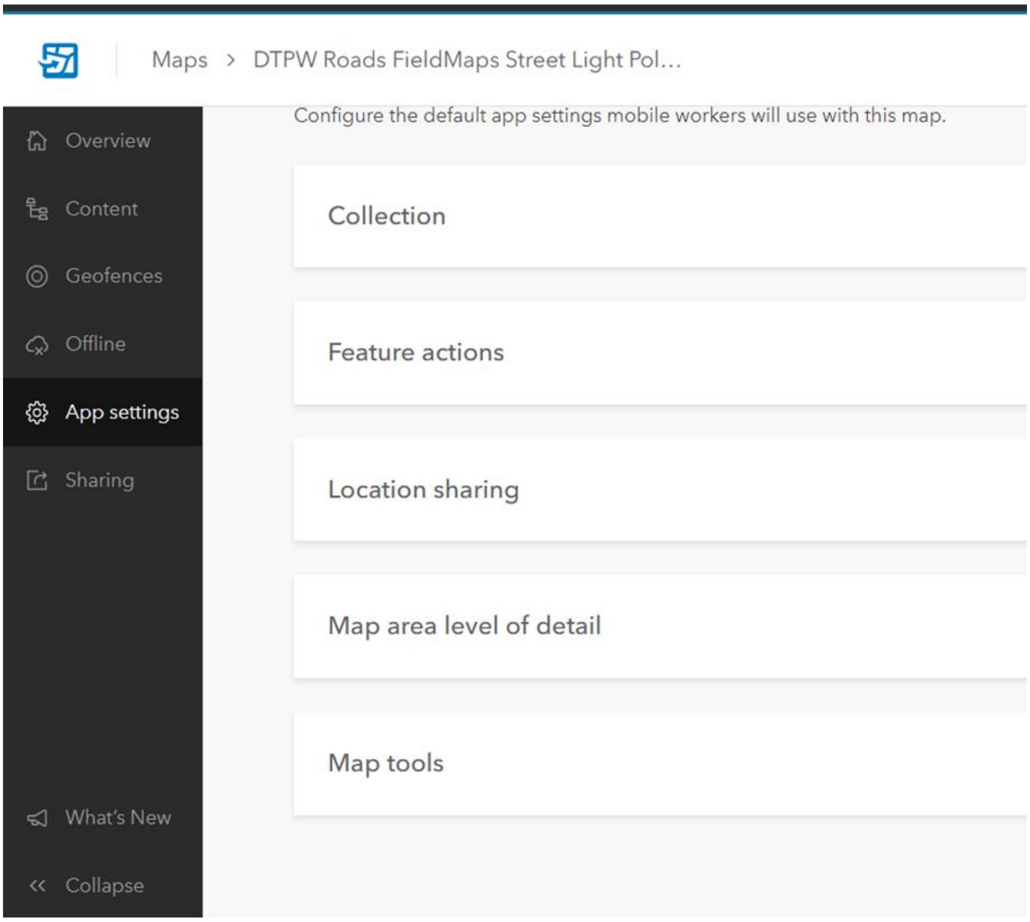


Figure 11: ArcGIS Field Maps Application settings

4.4.3 Configuring Application Sharing (Security):

The application is made available to field users, via the sharing menu in ArcGIS Online. User access is granted based on groups, which the ArcGIS Field Maps instance (and its data) and users are assigned to. This defines which users have access to which ArcGIS Field Maps instances on mobile devices. This further ensures that users logging into ArcGIS Field Maps have the appropriate permissions to access data consumed by the application. Users must have a Creator or Field Worker user type, as these provide the necessary rights to edit and update field data directly in the application.

These key configurations, enable a seamless experience for field users, who can efficiently add, edit, and manage data in the ArcGIS Field Maps application according to project requirements and security settings.

4.5 WCG Roads Streetlights Field Maps Application for Streetlight Capture

The final iteration of the ArcGIS Field Maps application developed for streetlight capture took the form of the "DTPW Road Traffic and Street Light Poles" application instance. Feature layers for traffic light poles were incorporated to enable the capture of these assets, as the fieldwork for streetlight data collection also covered areas where traffic light poles were present.

4.5.1 Capture Feature Classes and Base Data

Two feature classes were created to capture the streetlight and traffic light poles. A third master feature class of existing streetlight data was also introduced to indicate potential streetlight locations for verification. Additional reference or information layers were also included as these aid in data collection and can improve field work efficiency (Rossiter, 2022). Base data added to enrich the application web map and ease in field orientation and reference, were derived from Ersi standard base maps or existing map services present in the WCG Roads Portal (constituted mainly by the WCG road network).

4.5.1.1 Streetlight Capture Datasets

Table 1 and 2 shows the structure of the feature classes used for capture in "DTPW Road Traffic and Street Light Poles" application. These are the fields which the field works would populate during asset capture, with most being automatically generated. Appendix 1 provides a detailed overview of the various map and feature services that were required and published across different environments and platforms, as outlined in previous sections, to ensure the functionality of the Field Maps application.

Table 1: Streetlight capture feature class fields

TransGIS_AGOL.LDR.Light_Pole		
	Fields	
Display Name	**Field Name**	**Type**
OBJECTID	OBJECTID	ObjectID
Pole_ID	Pole_ID	String
GlobalID	GlobalID	GlobalID
Photos And Files	Photos And Files	Attachment

Table 2: Traffic light capture feature class fields

TransGIS_AGOL.LDR.Traffic_Light_Pole		
	Fields	
Display Name	**Field Name**	**Type**
OBJECTID	OBJECTID	ObjectID
Pole_ID	Pole_ID	String
GlobalID	GlobalID	GlobalID
Photos And Files	Photos And Files	Attachment

Figure 12 shows the two capture feature layers and base data collection included in an ArcGIS Online web map called 'DTPW Roads Traffic and Street Light Poles' which is consumed by the ArrGIS Field Maps application. This map is the interface field workers interact with on their mobile devices.

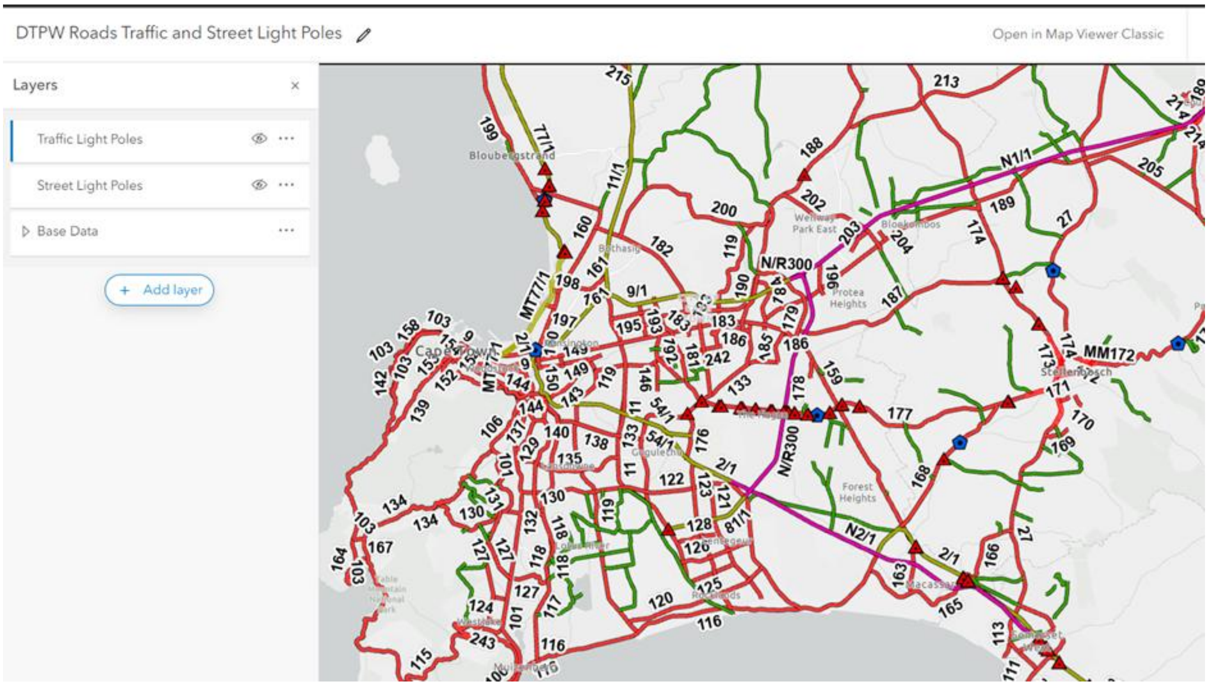


Figure 12: DTPW Roads Traffic and Street Light Poles web map

4.5.1.2 Existing Streetlight Dataset

A critical dataset incorporated into the application is a derived master feature class of existing streetlights, that serves as a visual guide and aids in navigating to potential streetlight locations. This feature class consolidates all existing records of streetlight locations and road sections containing streetlights, derived from contractor reports and archived data in the WCG RNIS. Despite the variability in (and lack of) attributes across these datasets, their primary purpose in the application is to provide a visual reference rather than detailed analysis. The existing streetlight data feature class was integrated into the Field Maps application alongside the capture feature classes. A new "Captured" attribute with a domain of "0" (default) or "1" was added to this feature class. This attribute enabled attribute-driven symbology, where features marked as "1" (indicating they had been captured in the primary capture feature class) were rendered with 90% transparency. This visual cue helped field workers distinguish between already captured data and uncaptured features.

The existing streetlight data layer could be toggled on or off within the application as needed. Thanks to the attribute-driven symbology, completed sections appeared faint on mobile devices, reducing visual clutter and minimizing confusion during fieldwork.

4.5.2 Field Maps Application Configuration Settings

The same form template was used for both traffic and streetlight feature classes, as both use the same attributes to capture streetlighting features. Figure 13 shows a simplistic yet effective form which minimises complexity in the field. It allows only for the entry of a Pole ID if applicable per feature captured. Such well prepared and customisable workspaces that still maintain user familiarity (throughout applications) facility reliable and efficient field capture (Nowak, et al., 2020) (Nielson, 2013).

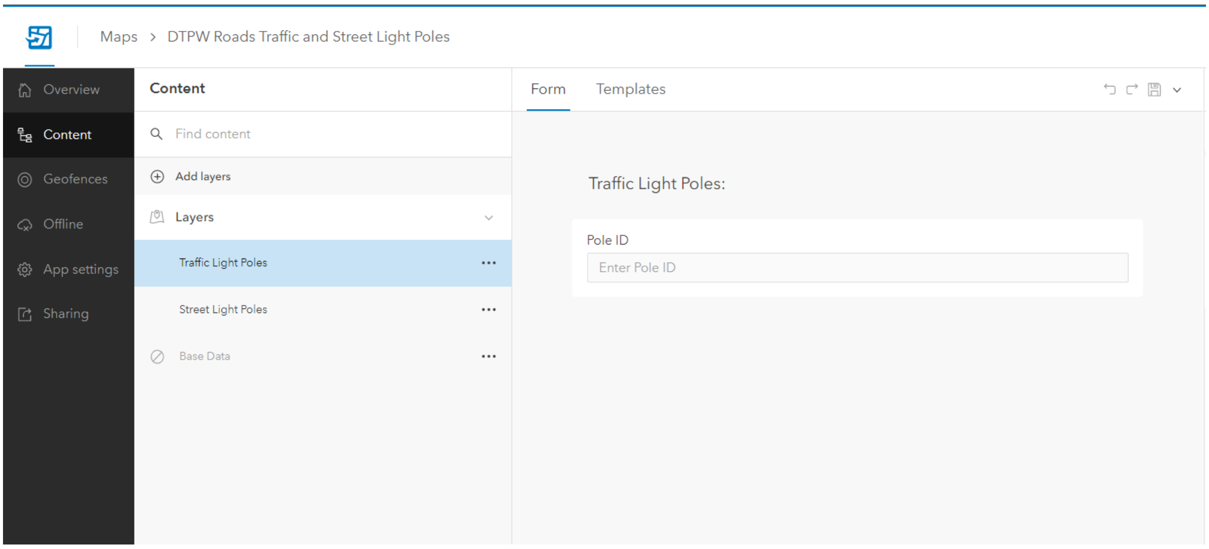


Figure 13: Form used in the DTPW Road Traffic and Street Light Poles application.

Further configurations specific to the DTPW Road Traffic and Street Light Poles" application include the following functional settings:

- The ability to capture data offline was disabled - while this factuality is pertinent, as echoed several times in literature, a technical limitation in the WCG GIS Environment made this functionality unusable. The interaction between the Organisation ArcGIS Online, Organisation ArcGIS Server and WCG Roads Environment that allows live data updates through the WCG domain, failed when the 'Offline capture' functionality was enabled in the Field Maps application. It was considered a higher priority to have a live data link, showcasing live update and tracking abilities of Field Maps, than to maintain the ability for offline data capture.

- Collection accuracy was changed from a 3.5m to a maximum of 4m. This was done due to preliminary test finding 3.5m accuracy being hard to achieve consistently while moving in a vehicle. As a compromise the number of observations was increased from 2 to 5 epochs, which are averaged to establish a features location. Filed capture optimisation in terms of accuracy, focuses on providing as accurate a dataset as possible for future use, rather than trying to meet only the minimum RNIS requirements of 25m. A 25m accuracy was also not practical in areas where streetlights are of a higher density with lights less than 20 meters apart, such as intersections, crossing or on roads near community buildings.

- As image capture was not part of the WCG Roads Directorate's scope for the Streetlight dataset, the image size was set the medium (this can be adjusted in the application as required) to conserved space in the dataset which would undoubtable contain several thousand features.

- Location snapping was disabled as the true locations of streetlight features are required to be verified 'as built'. The WCG Roads Directorate's aim specifically requires ground-truthed feature locations and not simply kilometre-values along the existing Road network.

- While editing is authorised on features previously captured, multiple or batch edits is disabled as a safety measure, to avoid bulk data loss in the event of accidental edits (multi feature selection) in the field.

5. FIELD WORK

Traditionally, like many local government agencies the WCG Roads Directorate relied on engineering surveys, conducted by skilled survey crews using specialised costly equipment, to obtain road asset information (Esri, 2022). The transition to a GIS environment that is functional, scalable, and cost-efficient has opened new possibilities for field data capture, including digitizing road assets from aerial imagery and capturing road centrelines and road furniture using GNSS technology. Although GNSS capture devices have been employed by WCG Roads for data capture, the post-processing requirements and data import complexities of non-integrated systems have often proven time-consuming and technically challenging.

From a field work and data capture viewpoint ArcGIS Field Maps simplifies the former complexities of field data capture by integrating GNSS-collected data directly into the GIS environment. This approach allows for the precise collection of points and attributes, removing the need for post-processing and minimising data entry errors, promoting data accuracy and consistency across the system. ArcGIS Field Maps also supports long-term data continuity by making data collection accessible and manageable, regardless of specialised knowledge in legacy systems. As a result, ArcGIS Field Maps enables field workers to easily maintain a dynamic, up-to-date, GIS database, ensuring the system's viability beyond legacy staff knowledge of non-integrated systems (Esri, 2022).

5.1 Defining the Capture Region and Locations

The WCG road network consists of over 7 281km of paved Road and near 24 936km of unpaved road, extending roughly 400km northwards along the Atlantic coast and 500km eastwards along the south (Indian Ocean) coast (WC RNIS, 2023). While streetlighting is not continuous along the entire network, it is present on sections throughout the network, including both paved and unpaved roads. Streetlighting is generally clustered around the entrances and exits to Towns, near road structures, intersections, and road furniture, with singular lights often inherited from legacy WCG uses (rail, docks or nature reserves). Figure 14 is an infographic representing the District Municipalities and the various road and road assets counts in the Western cape, indicating the regions and extent over which field capture takes place.

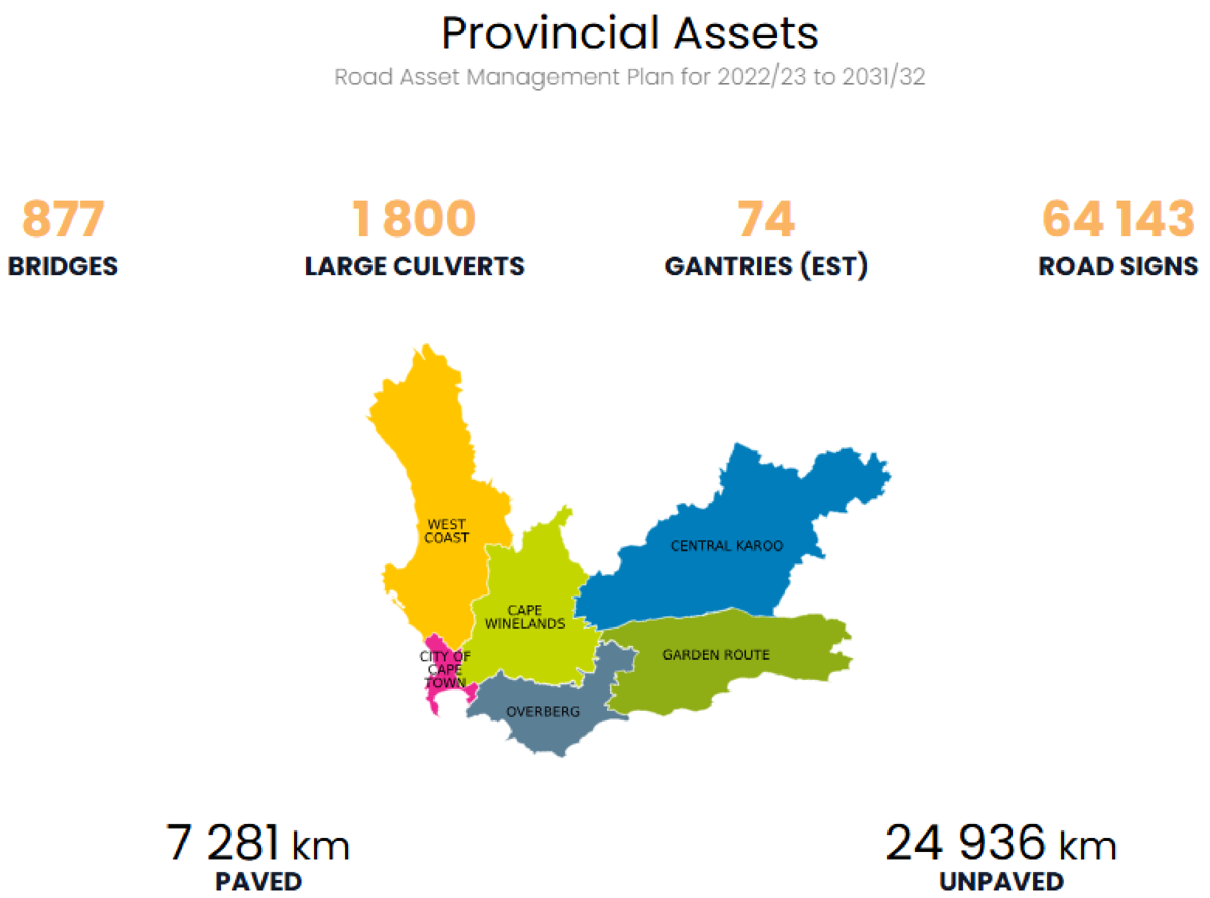


Figure 14: RNIS infographic of the Western Cape Road assets (WC RNIS, 2023)

5.1.1 Existing Streetlight Locations

The records currently available for streetlighting positions and sections was combined into a master feature class which guides the field work geographically. Majority of records were supplied in table format with kilometre values and road numbers as attributes per section, while other records came as maintenance project maps or design drawings of road sections. The various sources were combined making use of Esri ArcMap desktop GIS software to create a master feature class that was shared to the WCG Roads SDE. Table 3 indicates the format that data was received in, and Annexure 2 shows an example of mapped streetlight records received, which was manually captured with ArcMap digitisation tools. While some diagrams and maps contained coordinates that could be georeferenced, the accuracy was not required in compiling this feature class which is only intended as a guide.

The existing streetlight data, referencing the road sections based on kilometre values, was imported by means of events generated on the linearly reference WCG road network. Linear referencing is a method of storing distance related to a line feature, by modelling relative locations along linear features (Esri, 2023); Effectively superimposing a calibrated road length over the actual feature length. This is the standard way of generating features related to road sections. Coordinate points were imported in their native system. Several technical issues were recognised in data:

- Only positive car-way sections included when both negative and positive directions have streetlights present.
- Overlapping segments in terms of duplicated overlaps and segments within segments.
- Starting points of segments included without end points, which lead to segments being extended into other segments or extending till the road end point.
- Streetlights in median car-way sections not indicated.
- Erroneous or blank coordinates.

Table 3: Data provided for existing streetlights

ROADNO	CARWAY	STARTKM	ENDKM	L_TYPE_CODE	DESCRIP	LAT	LNG	COMM
OP05220	+	0,06	0,28	S14		-33,80805333	18,87359167	
OP05220	+	0,3	0,85	S14	Start Street Lighting	-33,80874667	18,87109167	
OP05281	+	0,03	0,13	S14	Start Street Lighting	-33,4392711	18,9629222	
OP05282	+	0,02	0,29	S14	Start Street Lighthing	-33,4391525	18,96338017	
OP05361	+	4,93	5,52	S14	Start Street Lights	-33,52938833	18,60020333	
OP05543	+	0	0,05	S14	Start Street Lights	-33,05994833	18,34174667	
OP05543	+	0,11	0,38	S14	Start Street Lights	-33,059425	18,34073667	
OP05705	+	2,36	2,56	S14	Start Street Lighting	-33,612135	19,446575	
OP05941	+	2,38	2,69	S14	Start Street Lights	-33,79513333	19,89538167	
OP06801	+	0,07	0,37	S14	Start Street Lighting			no coords
OP06802	+	0,01	0,37	S14	Start Street Lighting			no coords
OP06802	+	0,77	1,06	S14	Start Street Lighting			no coords
OP06802	+	1,08	1,64	S14	Start Street Lighting			no coords
OP06802	+	1,64	1,96	S14	Start Street Lighting			no coords
OP06868	+	0,9	1,02	S14	Start Street Lighting			no coords
OP06868	+	1,05	1,55	S14	Start Street Lighting			no coords
OP06887	+	0,03	1,35	S14	Start Street Lighting	-33,96815333	22,49140233	

The resulting master feature class of existing streetlight data was used in the ArcGIS Field Maps application for navigation and representation of sections to verify.

5.1.2 Mapping and Monitoring of Existing or Potential Streetlights

A desktop GIS project was created to serve as a central monitoring and mapping project, which consumed the master feature class of existing streetlight data. The project shows captured sections, with attribute driven symbology, as updated in the ArcGIS Field Maps application. Figure 15 illustrates the distribution of road segments potentially containing streetlights across the Western Cape, with the sections in green having been verified and captured, and the blue indicating sections yet to be completed. Figure 16 shows the identical stage of fieldwork, with the WCG road network displayed on the map in light blue. This map highlights the vast extent where fieldwork is required. 427 potential streetlight segments were identified across the network, with the largest concentration located in the District Municipalities of Cape Winelands, Garden Route and the Cape Town Metro.

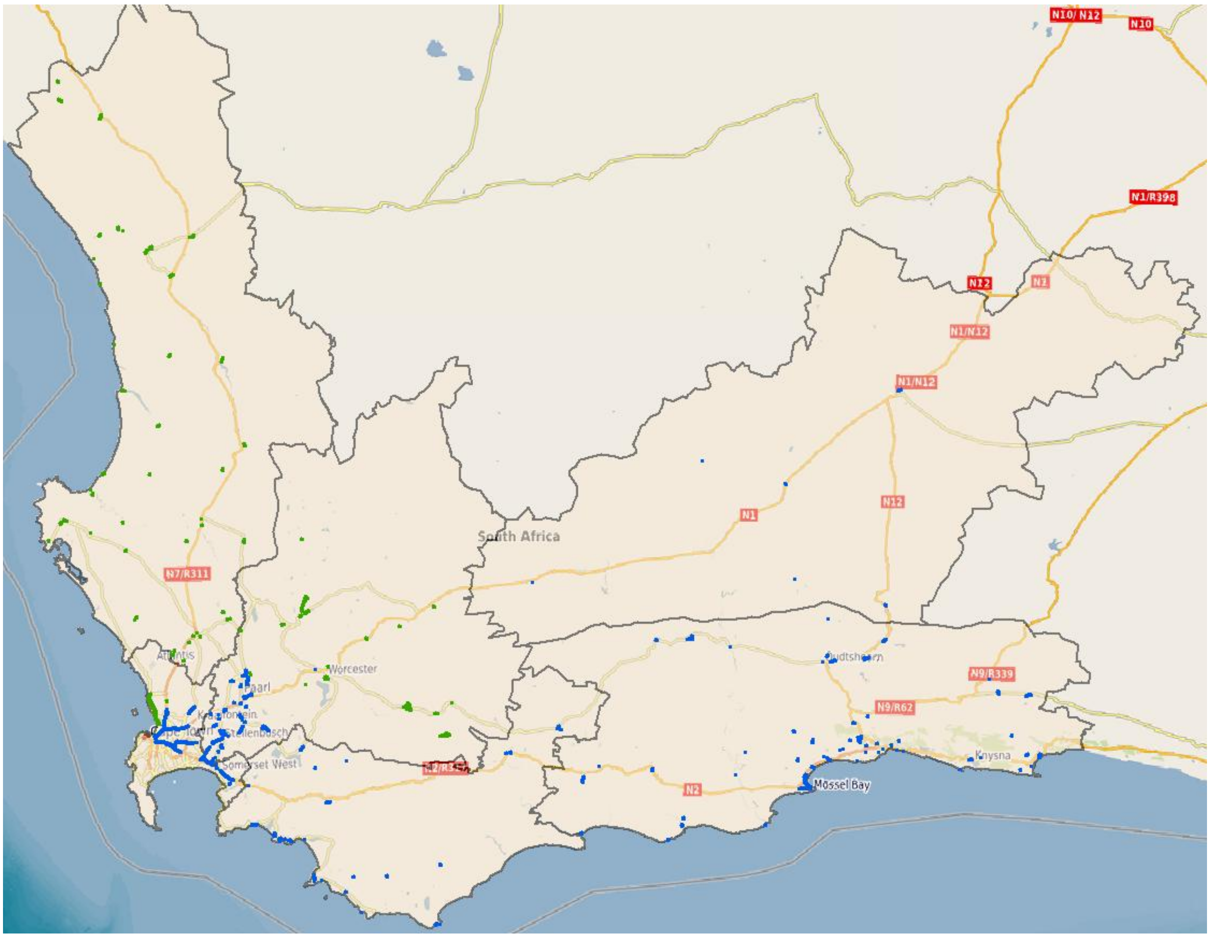


Figure 15: Road segments potentially containing streetlights

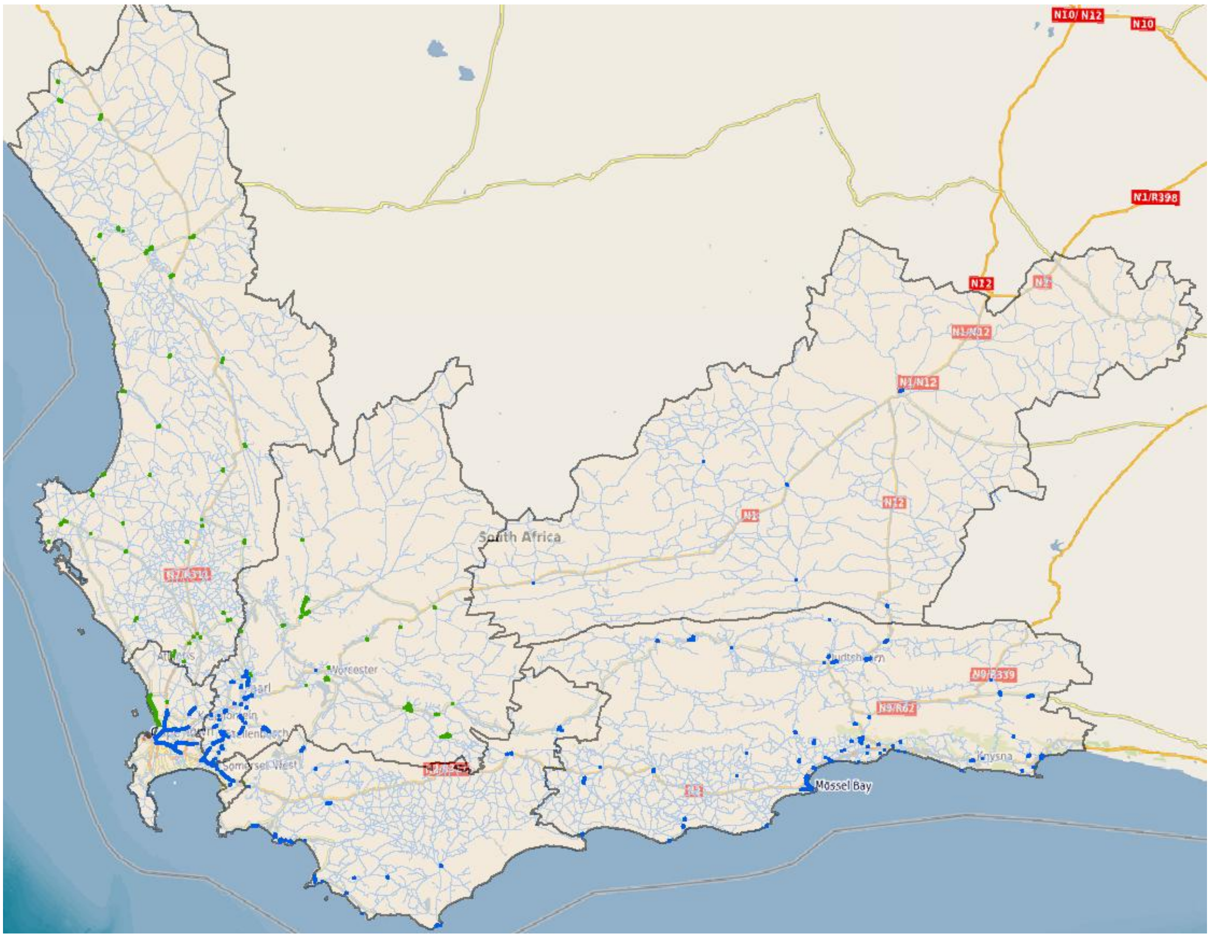


Figure 16: Road segments potentially containing streetlights and the WCG road network

5.2 Capture Methodology

The logistical approach adopted to capture streetlights integrated the capture process and field work into the daily operations of the WCG Roads GIS unit, rather than conducting capture as a standalone activity. As the dataset in not particularly time sensitive and human resources limited, the data capture portion was allocated two years to complete (2022-2023 period). The approach was to capture in a given area when field workers were required to either attend to alternative tasks in the area or could conduct the exercise in combination with other tasks such as training. This initial approach was reviewed due to the sheer volume of features and the capture being extremely time-consuming when conducted by individual field workers.

The restructured field work included two field works, one capturing with the mobile device and a second as driver. The schedule, while still relatively unstructured due to uncertainty of the number of features per area, focused on dedicating two weeks per month to data capture and working as far possible to complete a given District Municipality before moving to the next. Field workers would prepare by reviewing the GIS progress project, from which a route was planned to cover anticipated segments and additional alternative segments, if the segments proved to have no streetlight present or less than expected.

In terms of device usage and capture procedure the ArcGIS Field Maps application functioned effectively in the field, delivering live data updates to the capture feature classes. Ergonomics of the smart phone format proved ideal for the use case, requiring charging of the battery only once a day which was available in vehicle. Paper maps at local municipality level (derive from the potential master streetlight dataset) proved invaluable for in field navigation as often the WCG road network does not directly coincide with navigation software. These maps assisted field workers in regional positioning with the ArcGIS Field Maps application used to ascertain end and start points of potential streetlight segments once located. The poor quality of existing records made the base data, including the WCG Roads network, a critical part of field work. In areas where the WCG road network intersects with national roads and streets, field workers often needed to interpret changes in light type, the endpoint of the WCG road, or road furniture to determine which streetlights were part of the WCG road network. This identification was only possible by referencing the base data.

GNSS accuracy was generally achievable at the 4m requirement, however field works found it difficult to maintain this during summer months with GNSS availability dwindling beyond 5m at mid-day and in mountainous areas. It is speculated that solar flares and poor satellite geometry are the causes of these observations. This is not confirmed, as in certain cases using an alternative device improved accuracy. Nevertheless, this did cause delays in field work progress.

Mobile signal coverage was not consistent, particularly in the Northern parts of the West Coast district municipality, and rural and mountainous areas of Garden Route district municipality. The requirement for cellular data connectivity proved to be a flaw in the capture methodology, but necessary to provide the live connectivity desired in the GIS environment. Where cellular connection was lost, field workers were forced to note locations and manual added them to the feature class, when returning to the office.

Field workers compiled brief reports throughout the project both to monitor progress and to derive mitigation measures for issues experience. These reports, and a growing need for the authoritative streetlight repository, motivated the increase in dedicated resources and restructuring of the field work. Appendix 3 contains an example of the bimonthly reports submitted. The reports give a summary of experiences during field work, with a progress table indicating date, town, district municipality, status (complete) and comments – with the comments giving insight into the types (wood, cement or fibreglass poles) and the nature (not functional, broken pole or lens, etc.) of streetlight features encountered.

5.3 Field work Outputs, Monitoring and Adaptation

To improve monitoring and communication of field work progress to management, the GIS platform and analysis was already leveraged, during the data collection stage. Field work progress was reviewed not only via field reports and district municipality maps prepared bimonthly, but via a dedicated GIS Web Application developed as part of this study. The develop web application ‘Road Asset Management: Street/Traffic Light Poles’ was published to the WCG Roads ArcGIS Portal, serving as a tool to display the ‘live’ feature classes used for capture streetlights in the Field Maps application.

5.3.1 Capture Monitoring and Planning Web Application

The Road Asset Management: Street/Traffic Light Poles Web Application allowed for the progress of field work to be monitored in a real-time environment and in reference to a background of various base maps and related data, such as arial imagery and active project locations. This guided the field capture planning based on active projects or anticipated up grades, as certain roads sections where undergoing rehabilitation which included removal and or reposition of streetlights, which meant these streetlight sections could be ignored until construction is completed. Imagery also played a valuable role in planning routes that required walking capture, or navigation of complex local streets inside informal settlements. Field workers also shared photos to the web application as attachments to features, which could communicate any complex asset contexts back to office team. Figure 17 shows the Web Application Road Asset Management: Street/Traffic Light Poles, with the blue indicating areas of completed field work and red areas still to be completed.

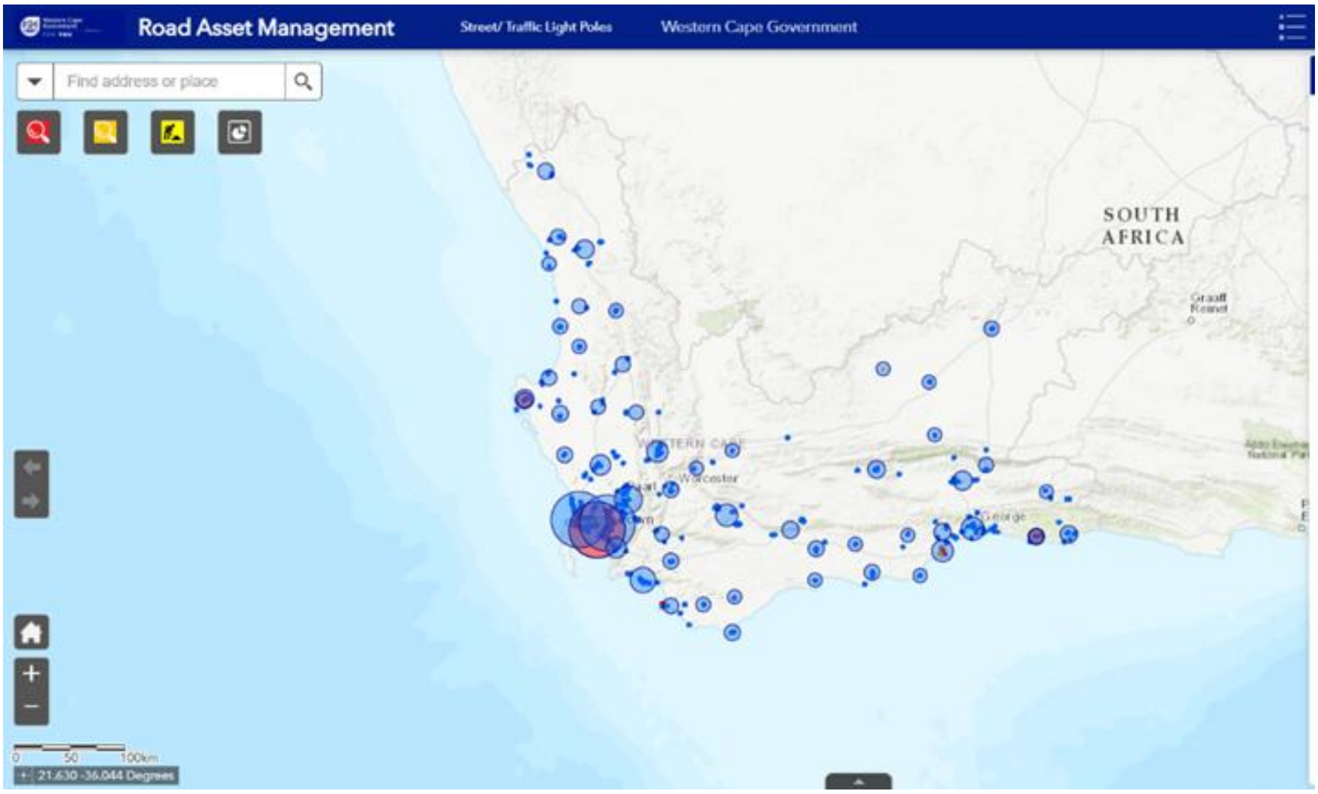


Figure 17: Web Application Road Asset Management: Street/Traffic Light Poles

The fieldwork was completed with the collection of all 427 potential streetlight segments, along with additional streetlight sections and point features identified in the field, based on the field workers' discretion.

5.3.2 Data Outputs

The key advantage of any GIS-based information system is its ability to show the relationships in data via a spatial component - Thus presenting the data in a way which is very difficult to achieve using a tabular database system, even when containing location based data (Alkhadour, et al., 2021). While GIS-based systems overcome their tabular contemporaries in this regard, at the core GIS data is still based on a tabular format that is spatially enabled, this means that many table based data management technologies can be utilised in data processing and integration. With each line in the spatial dataset's (feature class) attribute table representing the attributes of a given feature. Adding to the dataset is not limited to in-field capture but can be conducted and the feature manipulated at desktop level. The feature class used thus exists as a dynamic dataset yet is still securely maintained and controlled through versioning offered in the geodatabase/SDE, as in many standard database systems.

Features that could not be captured via the ArcGIS Field Maps application, due to loss of internet connectivity, are manually added to the feature class in Esri ArcMap, based on feature coordinates recorded. The initial data manipulation and analysis was conducted in ArcMap due to its lower hardware requirements and users' familiarity in dealing with data edits in ArcMap. ArcMap was also used to capture traffic lights in areas too dangerous for unescorted field work, which was accomplished by means of the City of Cape Town's (CoCT) 2023 25cm Ground sample distance (GSD) imagery. Remote sensing, making use of CoCT imagery, proved to be a highly effective method of feature capture. Spot checks conducted to verify data for approval by WCG Roads, showed deviations of up to only 1m.

The final field data took the form of two capture feature classes containing 9326 Streetlights and 979 Traffic Lights, respectively. The attribute 'Pole_ID' was only captured for a very small percentage of the features, as in most cases no ID was present on the pole. Further review by WCG Roads Asset managers indicated that the IDs collected did not serve to reference any dataset or system in WCG Roads Directorate, as initially anticipated, and as such was removed from the feature class. The images captured in-field, that took the form of attachments to features, served as method to communicate the context of streetlights when uncertainty in authority or technical issues presented. Feedback could be given to the field works or images shared with maintenance teams, however the scope did not intend for the images to form a permanent part of the streetlight repository as streetlights are theoretically continuously renewed. Figure 18 shows the capture feature classes' attribute tables.

Traffic_Lights_Poles

OBJECTID *	Shape *	GlobalID *
1	Point	{0371C05D-90D5-4656-98ED-08809AE95207}
2	Point	{7CE03679-F171-4CDF-AEF1-7F59BE0547A3}
3	Point	{86D44CBB-ADE5-4EB2-B6B5-8C36EE7C3AA9}
4	Point	{7AF38717-2C04-4DF6-81DD-6279F8369A41}
5	Point	{CFED1CF5-2F10-4480-BB99-ADD8AA81BB8E}
6	Point	{042895FD-B9D9-4E5F-9589-BEC5945C607C}
7	Point	{B5BC4805-3DA1-4337-8640-63B3116ABEC8}
8	Point	{8270B29F-695A-48EE-8449-ED50FDD7E7FE}
9	Point	{D7F25A6E-F002-4386-A70C-36B7BAB1C95F}
10	Point	{94B7B199-B3A6-4788-A8E0-C54449559E15}
11	Point	{9BF1FEA7-8D2E-4012-80A7-78435DD6CC4B}
12	Point	{ACC2018B-71A7-43C5-A01C-53F77FD9F3B0}
13	Point	{29EF3913-5E2B-4086-BC62-58878D679F3C}
14	Point	{CFC08962-FC11-4D59-83FA-A344DEA667AF}
15	Point	{214BCF8B-6865-484F-8157-32AC6D66D996}
16	Point	{CAA9E76A-8364-4C7A-801B-4FCE5C5F90AA}
17	Point	{F65FAF04-989A-445B-8B92-E383D735AC7A}

0 (0 out of 979 Selected)

StreetLights_Poles

OBJECTID *	Shape *	GlobalID *
1	Point	{3B0D2370-C0C4-4B49-BB71-DB0F622BAE06}
2	Point	{95C4D283-CA8D-4B60-86B5-42760080883F}
3	Point	{82705239-14BE-45F3-A0A6-24B94BDDDE93}
4	Point	{032FF7BD-23A1-4549-BC7A-C50BF504F976}
5	Point	{3AAAF451-9BF3-41E9-86C1-4EB1DCA89254}
6	Point	{9DA66739-9F2D-4FE0-966B-C67DC60CFF36}
7	Point	{A66A88A9-7B63-4660-8151-BEC75C595928}
8	Point	{38DC0577-DFE3-4D90-9D8B-A8ECF183F38A}
9	Point	{27D89431-DB2A-4DAD-8267-B0446FEA8A9C}
10	Point	{7D29FADE-2A10-43D2-BD82-5612C36A42FB}
11	Point	{6F95C7DE-686F-4B6D-9F8D-7268FDEE3CF3}
12	Point	{985E3AB4-1752-4F99-99C8-84AA14C2CAA4}
13	Point	{63458ACC-1F44-4F51-AC2F-034DBDFDA8B6}
14	Point	{62DF9A5D-36D2-4063-96AC-0ECC782C6F4F}
15	Point	{CC29394B-B001-4899-86F6-DE19D3EFA053}
16	Point	{BBA49702-7FE2-46AF-89E5-A9638F884EB0}
17	Point	{E2FE187B-F40C-4533-B12C-8BDD257D8876}

0 (0 out of 9326 Selected)

Figure 18: Attributes tables of raw captured streetlight data

6. DATA ANALYSIS

The asset dataset collected during fieldwork, while validated for accuracy and consistency, is not suitable for analysis in its raw form. While the Esri environment facilitates the creation of technically robust and high-integrity data (through processes such as customised feature class creation in ArcGIS Pro and data capture using the ArcGIS Field Maps application); the raw streetlight dataset still requires the addition of specific attributes to ensure it is fully functional within the broader GIS system and ready for inclusion in the central repository. This process is accomplished through various spatial analyses conducted within the Esri desktop software.

The data analysis is structured into three key components: associating related attributes, streetlight analysis, and road network analysis. The primary goal is to enhance accessibility to streetlighting data by enriching, presenting, and leveraging it in GIS tools that can support decision-making processes. The following section breaks down the utility of the three analysis components:

1. Association of Related Attributes - This foundational step prepares the data for further analysis by establishing relationships with the road network through common attributes. This process creates the core datasets that form the basis of the streetlight repository, ensuring the data is organised and prepared for subsequent analyses.
2. Streetlight Analysis - This component involves using location-based GIS tools to explore the dataset, focusing on deriving quantitative insights and analytical aspects. It provides a deeper understanding of the spatial distribution and characteristics of streetlight assets.
3. Road network Analysis - This analysis evaluates the data in the context of the road network. By applying GIS tools, it examines the relationship between streetlighting and the road network, assessing factors such as illumination coverage and streetlight density, demonstrating its potential impact on roadway conditions.

The second and third components specifically aim to analyse streetlight illumination conditions. They serve as a proof of concept for GIS-based analysis, showcasing the potential of GIS to provide actionable insights and metrics. The ultimate objective is to illustrate how

GIS tools can inform strategic planning and decision-making for streetlighting and related infrastructure.

6.1 Streetlight Attribute Association

The scope of streetlight feature capture was limited to feature location, with an initial intent to capture any Pole IDs indicated as well. The field data results showed that very few Pole ID's where captured, with the attribute subsequently dropped and as such the raw dataset contains only system unique identifiers and the spatial attribute. While the dataset is intended to constitute the foundation for a growing streetlight repository, which contains a multitude of data attributes including technical aspect of pole and lamp type and condition, currently it only contains a spatial location. Attribute association aims to link the locations of streetlights with the respective roads they serve on the WCG road network and will be the first of future value-adds to the repository.

Making use of spatial join analysis, which joins attributes from one feature to another based on their spatial relationship, point features (representing streetlight pole locations) in the streetlights feature layer were joined to both the WCG road network feature layer and the streets feature layer (constituted by the WCG street dataset). The spatial join matches rows from the join feature's attributes to the target feature's attributes based on their relative spatial locations (esri, 2024). The match option parameter is set to 'Closest', where the feature in the join features that is closest to a target feature will be matched (esri, 2024).

To determine which two features are closest to each other, geoprocessing tools establish the distances between any surrounding two features, with any given distance calculated as the shortest separation between two features (esri, 2023). As the feature layers being analysed have a geometry type of lines and points respectively, the distance from a point to a line is defined as either the perpendicular or to the closest vertex on a line. The geoprocessing is most accurate when the input data is in an equidistance projected coordinate system, while data in a geographic coordinate system may lead to inaccurate or even meaningless results (esri, 2023). The analysis was conducted in the UTM_Zone34_South projection that makes use of meters as the standard of measurement.

The Join operation was limited to a one-to-one relationship which is interpreted as when multiple join features are found that have the same spatial relationship with a single target feature, the attributes from the multiple join features will be aggregated using a field map merge rule (esri, 2024). However, in the case of 'Closest' matching when two or more join features are the same distance from the target feature, one of the join features will be randomly selected as the matching feature. Thus, no attribute aggregation is required to maintain a one-to-one relationship. Effectively these parameters maintain that each streetlight is assigned relevant attributes without duplication.

The spatial join analysis was completed and the additional attributes cleaned and arranged in the final streetlight feature dataset, in the form indicated by the attribute table shown in figure 19. The critical attributes that enable queries to be developed and filters to be applied are the following:

- Road Number and Segment ID, which are used as a unique IDs across all WCG Roads Systems.
- A further critical attribute is Town Names as this defines the regional road authority, informing where the responsibility lies and high-level planning which is based on geographic areas.
- Street and Road names, while not critical, contribute greatly to maintenance planning, as reports and complaints often uses address and street names or road names rather than km values.

ROADNUMBER	ROADNAME	AREA_NAME	TOWN_NAME	NAME	FULL_NAME	ROUTEID	STREETNAME	SEGMENT_ID
MR00177	<Null>	Stellenbosch Central	Stellenbosch	ADAM TAS	ADAM TAS STREET	R310	<Null>	42
MR00177	<Null>	Stellenbosch Central	Stellenbosch	ADAM TAS	ADAM TAS STREET	R310	<Null>	42
MR00177	<Null>	Stellenbosch Central	Stellenbosch	ADAM TAS	ADAM TAS STREET	R310	<Null>	42
MR00177	<Null>	Stellenbosch Central	Stellenbosch	ADAM TAS	ADAM TAS STREET	R310	<Null>	42
MR00215	<Null>	Darling	Darling	LONG	MAIN ROAD	R315	<Null>	13
MR00215	<Null>	Darling	Darling	MAIN	MAIN ROAD	R315	<Null>	13
MR00215	<Null>	Darling	Darling	MAIN	MAIN ROAD	R315	Main Street	13
MR00215	<Null>	Darling	Darling	MAIN	MAIN ROAD	R315	Main Street	13
MR00215	<Null>	Darling	Darling	MAIN	MAIN ROAD	R315	Main Street	13
MR00215	<Null>	Darling	Darling	MAIN	MAIN ROAD	R315	Main Street	13
MR00215	<Null>	Darling	Darling	MAIN	MAIN ROAD	R315	Main Street	13
MR00215	<Null>	Darling	Darling	MAIN	MAIN ROAD	R315	Main Street	13
MR00215	<Null>	Darling	Darling	<Null>	MAIN ROAD	R315	<Null>	13
MR00215	<Null>	Darling	Darling	STATION	MAIN ROAD	R315	Main Street	13
MR00215	<Null>	Darling	Darling	STATION	MAIN ROAD	R315	<Null>	13
MR00215	<Null>	Darling	Darling	<Null>	MAIN ROAD	R315	<Null>	13

Figure 19: Final streetlight feature class attribute table

The feature class for traffic lights captured at intersections underwent the same spatial join analysis, as described for the streetlights, to establish similar attributes. In addition, a feature class containing centroids for each traffic light intersection was manually digitised in Esri ArcPro as an accompanying dataset. This Traffic Light Set dataset also underwent the same spatial join analysis.

6.2 Streetlight Analysis

Having established a streetlight feature layer with necessary attributes, analyses can be conducted in terms of the location and distribution of streetlights along the WCG road network. As noted in the previous sections no specific technical attributes of the individual streetlight features have been established. Yet by assuming general variables in terms of the light distribution type and suitable pole height, based on assumed fixture and bulb wattage, light coverage analysis can be conducted.

To establish light intensity, spatial tools are employed to combine the locations and results for coverage, to map regions of varying intensity. Traffic intersections are areas of activity which are prone to accidents and as such establishing a relative coverage will inform planning. This analysis aims to showcase the application of geospatial techniques and tools at both large and small scales, utilising necessary assumptions and disregarding external factors to facilitate the establishment of a methodology.

6.2.1 Streetlight Location

Street lighting locations were mapped over Esri World imagery and the WCG road network, to offer visual context of the spatial distribution of streetlights across the WCG road network. The streetlights are symbolised with scale-based illumination characteristics, allowing for viewing at local and regional municipal level as-well-as province wide, while maintaining spatial legibility. Figures 20 and 21 show the streetlight mappings at various scales.

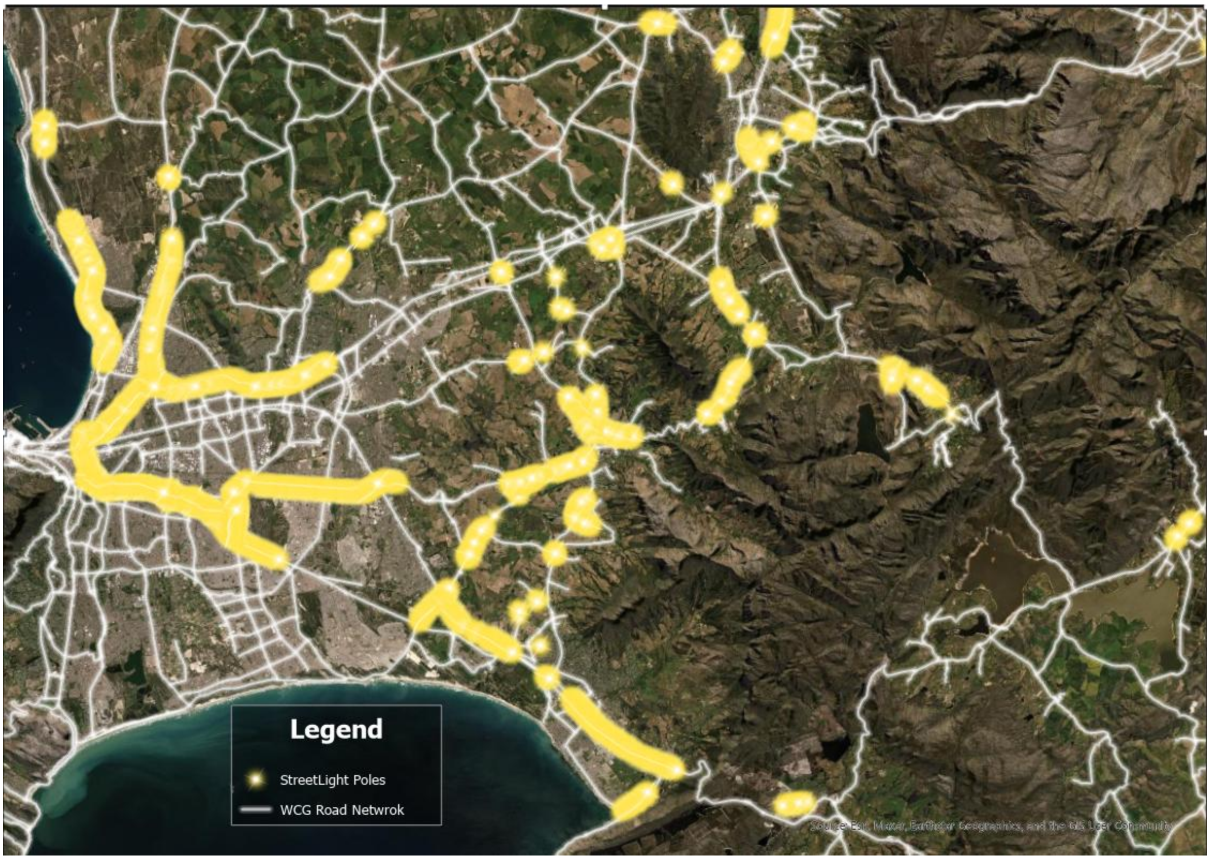


Figure 20: Streetlights mapped in the great Cape Town Metro

To aid in visual analysis a stacked symbology was developed for streetlight features, which is applied at the 1:2 000 scale (a suitable scale for planning), and represents the estimated extent of the streetlights' luminaires on the ground surface. Figure 21 shows a portion of municipal trunk road 77/1 at the scales 1:5 000 and 1:2 000, showcasing the luminaires introduced at 1:2 000.

Figure 21: Streetlights on a portion of trunk road 77/1 at the scales 1:5 000 and 1:2 000

The visual representation capabilities of GIS, combined with the integration of related real world spatial data, facilitates the visual interpretation of the data and spatial contextualisation, when undertaking initiatives in a specific area. This visualisation allows for observation-based analysis – often users and decision makers hold expertise, which make visual assessment and analysis some of the key aspects that drive planning and decision making. Figure 22 demonstrates the streetlights in an interchange (N7 and N1 roads) which cannot be observed as a whole in the field due line-of-sight obstructions. Figure 23 demonstrates clearly where breaks in the pattern of streetlight spacing is occurring. In each case the interaction between lights is observed through location based mapping and curated representation, achieved via customised GIS feature symbolisation.

Figure 22: Streetlights in the N7 and N1 interchange

Figure 23: Streetlight spacing on the N1

To facilitate visual analysis of streetlight locations by users, the 'Road Asset Management: Street/Traffic Light Poles' Web application previously developed and hosted in the WCG Roads Esri Portal, was redeveloped into the web application 'Asset Management – Street/Traffic Lights' which includes the data enhancements documented in this section. The applications datasets and functions are documented in appendix 4.

6.2.2. Illumination Characteristic Assumptions

The analysis of streetlight coverage and intensity is conducted with standard light fixture variables assumed across all features. These generalised variables were derived from observations made in the field and the standards outlined by the Illumination Engineering Society of North America (IESNA). The IESNA defines five light distribution types or patterns which outline how light is dispersed from a fixture, which is defined by the points at which 50% of the fixture's luminous intensity is met (SUDAS, 2020) (Wo, 2020). The type three distribution is generally favoured for large multi lane roadway and highway lighting, which constitutes the majority of the WCG Streetlights. The type three distribution is optimised for a ratio of 2.75 between the illumination area's width and the pole's height, effectively covering a road width up to 2.75 times the height at which the bulb is mounted (SUDAS, 2020) (Wo, 2020). While not verified, many older fixtures were observed to be 250W high-pressure sodium streetlights, with most light fixtures in the Cape Town Metro having been replaced with 100W LED fixtures that offer an equivalent luminance intensity to the high-pressure sodium streetlights. Fixtures of this wattage are suitable for a pole height 8m-10m, which was roughly the height of most streetlights captured (Gong, 2021).

To establish the values for light throw/distribution used in the coverage and intensity analysis sections, the product of pole height and 2,75 was taken. Poles were estimated to be 8m and 10m, resulting in an operational light throw of 22m and 28m. These values where applied to all streetlights in the execution of geospatial tools and calculations. However the analysis could for each feature derive input values from variables in the attribute table, that could be unique for each streetlight feature.

While the type three distribution generally has an oval shaped light pattern, with each model of fixture having its own specific light pattern, for simplicity the light pattern is represented by circles centred around the light feature with a diameter defined by the operational light throw. This is not a limitation in the software as Esri ArcPro possess the ability to incorporate manufacturer photometric files with precise light patterns. However, maintain average illuminance and uniformity, in light patterns at a network level, aids comparative analysis of regions (Saraiji, et al., 2009).

6.2.3 Light Coverage

To derive streetlight coverage a spatial buffer analysis was conducted. The process creates buffer polygons around input features to a specified distance. The process was conducted at both 22m and 28m making use of Euclidean buffers, which measure distance in a two-dimensional Cartesian plane (planar distance). This method provides more accurate results and was possible due to input features having a UTM projected coordinate system (ArcGIS Pro, 2024). The outputs were dissolved so as to form continuous coverage polygons.

Figure 24 shows the coverage polygons datasets in a large interchange. The polygons are symbolised to represent individual light patterns while being combined in lager coverage polygons. The polygon edges show two boundary lines, which is due to both the 22m and 28m light coverage datasets being overlaid in the figure. Viewing this data in GIS indicates clear areas that lack coverage, with certain bridge and slipway sections lacking coverage despite a relatively large number of streetlights along the road sections. This analysis provides a practical measure of the theoretic extent of lighting patterns.

Figure 24: 22m and 28m streetlight coverage polygons in a large interchange

6.2.4 Traffic Intersection Light Coverage

To establish a quantitative measure of light coverage in traffic intersections an analysis is conducted, which establishes the frequency of streetlights in the area surrounding the intersection. This is achieved by means of spatial join analysis (as described in section 6.1), in this case joining no attributes but using the spatial relationship between the traffic intersection set features (intersection centroids) and surround streetlight features. The method used a 28m join radius, as per the largest light pattern, around the intersection sets dataset features. The resulting number of joins, incremental for every streetlight in the radius of the intersection set features being analysed, was added as a join-count attribute.

The result is a point dataset that can be symbolised based on the number of joins, effectively indicating the lighting coverage per intersection, based on a qualitive value. The result was binned into three levels, which showcases the ability to integrate design and planning thresholds and flags for asset managers. Figure 25 illustrates the dataset, which indicates that while streetlight density may appear similar across intersections, this analysis indicates a lighting coverage difference based on quantitative spatial measures. Inset 1 in figure 25 showcases that a road that visually presents a relatively consistent distribution of streetlights may have great variation in actual light coverage of intersections. The analysis identifies and classifies intersections by light coverage without the need for a one-by-one investigation.

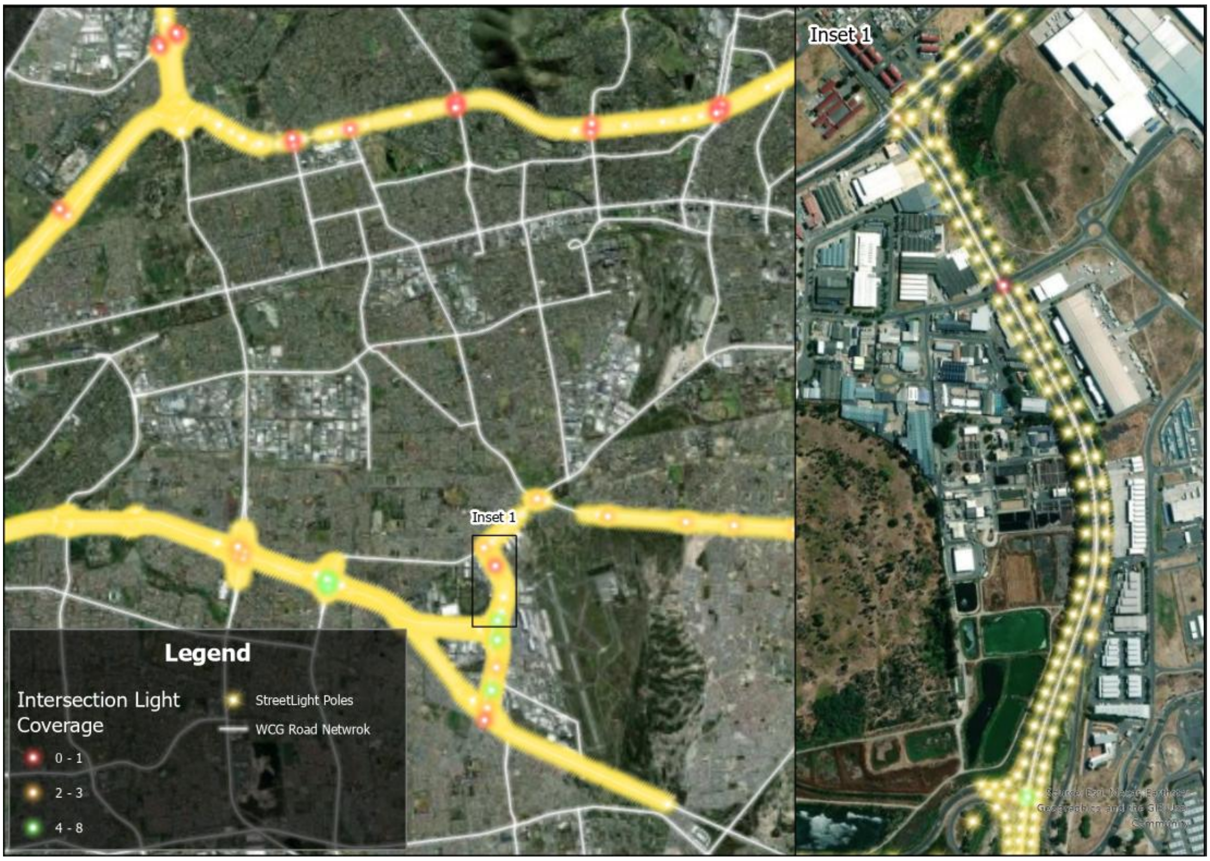


Figure 25: Light coverage of traffic intersections

6.2.5 Light Intensity

To derive streetlight intensity, a spatial buffer analysis was conducted in a similar way as described in section 6.2.3. but the method differed in that the outputs where not dissolved, there by preserving the individual light pattern polygons. The analysis assumes that each streetlight has an equal, unobstructed and continuous output throughout the pattern, thus by overlaying the light patterns the cumulative light intensity will be visually apparent. Figure 26 displays the resulting dataset which shows regions of greater overlap appearing more intensely coloured (less transparent) or obscuring more of the imagery layer below. A more technical evaluation can be visually derived from the overlapping boundaries or density of boundaries along given sections of road.

Figure 26: Visualisation of streetlight intensity

While the result provides a visual representation of intensity, the data can be further interpreted by means of Overlapping Count Analysis, producing a spatial result that can be expressed quantitively. This analysis counts over lapping features in a dataset, generating planarized overlapping features from the input, with the respective count of overlaps written as an attribute to the output features (ArcPro, 2024). The resulting dataset is symbolised based on the overlap count to indicate regions of varying intensity, effectively quantifying what was previously visually discernible. Adding a numerical count and spatial region, allows further statics to be drawn and allows the data to be integrated with other road systems. Figure 27 shows the result overlayed over initial intensity buffers, with the intensity of overlapping polygons symbolised from yellow to red, based on number of overlapping streetlight buffers.

Figure 27: Intensity buffers and overlapping polygons symbolised

6.3 Road network Analysis

GIS analysis of the streetlight dataset, as presented in the formed sections, provides insight into intensity and coverage in the spatial domain surrounding, and covered by, the streetlight features. However, all initiatives and projects of the WCG Roads Directorate are related to road segments on the WCG road network. Subsequently analysing streetlight data in terms of its effect on the road network provides a context desired by decision makers for planning and operation.

The focus of this analysis is to demonstrate the application of geospatial techniques and GIS tools that can provide quantitative data and a general overview of lighting infrastructure at various legislative levels. Spatial tools are employed to analyse the quantity of streetlight assets along individual roads and to establish a road illumination percentage. The results of which inform the status of a road both in terms of lighting and lighting infrastructure.

6.3.1 Road Streetlight Quantity

To establish the number of streetlights along each road an analysis is conducted, which evaluates the occurrence of streetlights along the road, based on spatial intersection. This is achieved by means of spatial join analysis (as outlined in section 6.2.3), using the spatial relationship between road buffer features (an estimation of the road reserve) and surrounding streetlight features. Road buffers are ideally generated from the WCG road network dataset, using the road reserve width assigned to each road type. However, as a comprehensive road reserve dataset is not available, a standard width of 50m was applied as this would encompass all streetlight features which is the primary objective. The join was based on the intersection of the streetlight features with the road buffers, with the resulting number of joins (incremental for every streetlight intersecting a road buffer), added as a join-count attribute to that road buffer. Figure 28 shows generated road buffers and streetlight features which intersect.

Figure 28: Road buffers and intersecting streetlight features

The join-count attributes are then added with the WCG road network dataset by means of a relate function based on the Road Number identifier. This allowed for the symbolisation of the road network based on the number of streetlights assigned to a particular road. Figure 29 shows the Road network symbolised in this manner, with the classes defined by natural breaks in the data.

Figure 29: Streetlights per road

While a purely analytical approach may deliver the same result, by counting the number of entries of each road number in the attributes of the streetlight dataset, it would lack the spatial perspective. The result of this analysis combines the spatial aspects of distance and distribution of roads with the quantitative result, effectively providing context and ground-based evidence for a particular roads streetlight quantity.

6.3.2 Percentage of Road Illumination

To establish the percentage streetlight cover for each road, an analysis is conducted which calculates the total length of lines within a polygon. Intersect geoprocessing is used to isolate the sections of road which intersect with the coverage polygons dataset, which represent streetlight light patterns. Using the geometry calculator a length attribute was added to the attribute table of the intersect geoprocessing output. These attributes are then joined to the original road network dataset based on ID, after which the field calculator is used to calculate the percentage in terms of the 'road length' and 'road length intersecting light patterns. The road network is then symbolised based on percentage of road illuminated per road, in classes of 20% as shown in figure 30.

Figure 30: Percentage of road illuminated

While communicating what percentage of a road is illuminated, the result also has the effect of indicating which roads contain any streetlights. This is achieved by not symbolising roads with 0% illumination coverage.

6.3.3 Streetlight Density

Point Density analysis, which is part the AcrPro Spatial Analyst tools, calculates a magnitude-per-unit area from point features that fall within a neighbourhood around each cell. Only the points that fall within the neighbourhood are considered when calculating the density. If no points fall within the neighbourhood at a particular cell, that cell is assigned NoData (ArcGIS Pro, 2024). The tool performs density analysis based on five key parameters; table 4 lists and describes the parameters and indicates the values used for each.

Table 4: Density analysis parameters

Parameter	Value Used	Explanation
Input Point Features	Streetlight Poles Feature Class (Points)	The input point features for which to calculate the density.
Output cell size	10m	The cell size of the output raster that will be created.
Neighbourhood	Circle with a radius of 250m	Dictates the shape of the area around each cell that is used to calculate the density value. In this case circular neighbourhood is used with the given radius.
Area units	Square kilometres	The area units of the output density values – applying a scale factor.
Environment Mask	Road network buffers (50m wide)	The Mask is used to indicate the cell locations that will be included when performing an analysis. All cells that fall outside the mask are assigned the No Data value. Effectively this defines the region of analysis.

Conceptually, the analysis establishes a neighbourhood around each raster cell centre, and the number of points that fall within the neighbourhood is totalled and divided by the area of the neighbourhood (Silverman, 1986). The intent is to limit the analysis to the liner road sections;

thus, the mask is used to define the region of 50m width along the road lengths. This region width along with the assumed road width, as per TMH 16 requirements for two-lane Class 4 road of 10.2m (COTO, 2012), was considered to determine the output cell size of 10m. This cell size allows for 5 cells across the region, roughly accounting for each lane and sidewalks in the largest road class.

The neighbourhood was defined with a radius of 250m, considering the mask, effectively establishing an analysis neighbourhood of 500m x 50m. This neighbourhood size was based on field observations of line-of-sight to surrounding streetlights. Changes in the radius will not greatly alter the calculated density values; as more points will fall within a larger (longer) neighbourhood, this number will be divided by a larger area when calculating density. The main effect of a larger radius is the more generalised output, as the density is calculated considering a larger number of points, which can be farther from the raster cell (Silverman, 1986).

The resulting streetlight point density raster is symbolised based on natural breaks with values indicating the number of streetlights per square kilometre. Figure 31 shows the resulting raster layer with Inset 1 showcasing the resolution at intersection or interchange level.

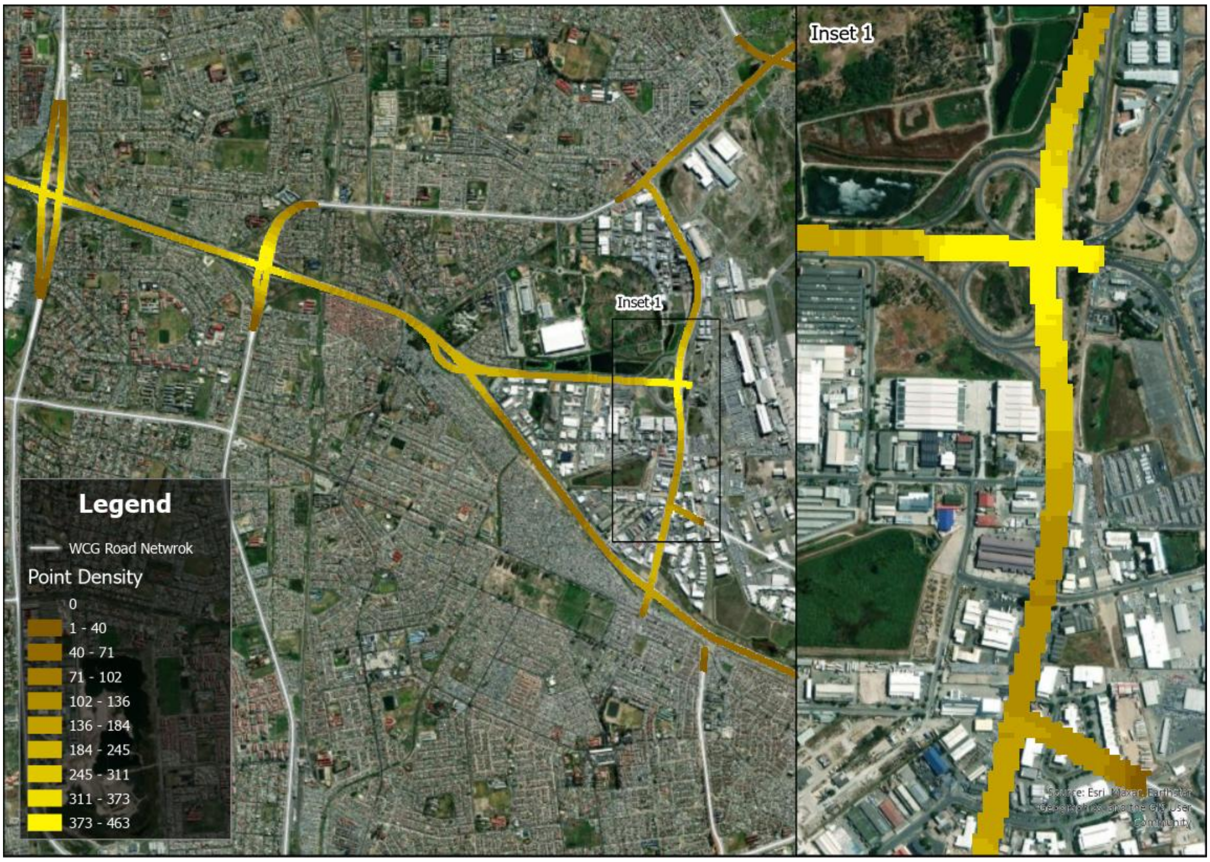


Figure 31: Streetlight point density

6.3.4 Road Lighting Hotspots (Kernel Density)

To determine 'hotspots' in the streetlight data a kernel density analysis is conducted, which forms part of the AcrPro Spatial Analyst tools. It calculates a magnitude-per-unit area from point features using a kernel function to fit a smoothly tapered surface to each point. Only the points that fall within the neighbourhood are considered when calculating the density. If no points fall within the neighbourhood at a particular cell, that cell is assigned No Data (ArcGIS Pro, 2023).

The outputs of Point Density and Kernel Density differ:

- Point density specifies a neighbourhood that calculates the density of the population around each output cell (ArcGIS Pro, 2024).

- Kernel density spreads the known quantity of the population for each point out from the point location. The resulting surface surrounding each point in kernel density analysis is based on a quadratic formula, with the highest value at the centre of the surface (the point location) and tapering to zero at the search radius distance. For each output cell, the total number of the accumulated intersections of the individual spread surfaces is calculated (ArcGIS Pro, 2024).

The Kernel Density tool performs a density analysis based on seven key parameters; table 5 lists and describes the parameters and indicates the values used for each.

Table 5: Kernel Density analysis parameters

Parameter	Value Used	Explanation
Input Point Features	Streetlight Poles Feature Class (Points)	The input point features for which to calculate the density.
Output cell size	10m	The cell size of the output raster that will be created.
Search radius	250m	The search radius within which density will be calculated
Area units	Square kilometres	The area units of the output density values – applying a scale factor.
Output cell values	Densities	The output values represent the calculated density value per unit area for each cell
Method	Planar	The planar distance between features will be used
Environment Mask	Road network buffers (50m wide)	The Mask is used to indicate the cell locations that will be included when performing an analysis. All cells that

		fall outside the mask are assigned the No Data value. Effectively this defines the region of analysis.

The output cell size and environmental mask values were derived in the same way as described in section 6.3.3. The Neighbourhood search radius was set to 250m for the same reasons presented in 6.3.5. While different methods are used to calculate density, maintaining a consistent size in the region of analysis, should allow for relatively comparative result.

The resulting streetlight hot-spot raster is symbolised based on natural breaks with values indicating the smoothed kernel density of streetlights per square kilometre. Figure 32 shows the resulting raster layer over various roads and intersections. Inset 1 showcases the same region as in Figure 31 Inset 1 and illustrates how the Kernal density defines hot and cold sections as opposed to the point density which is more cell specific.

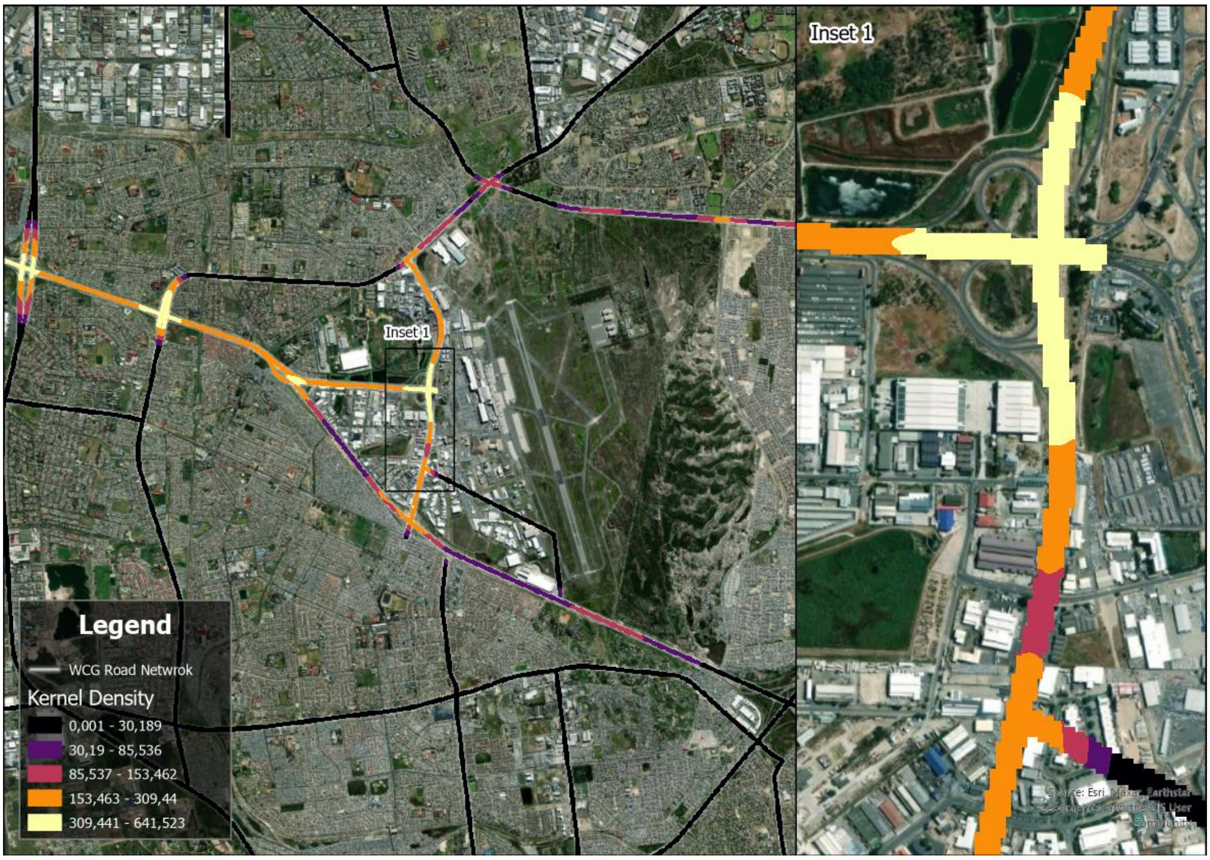


Figure 32: Streetlight kernel density

7 RESULTS AND DISCUSSION

7.1 Field Maps Application and Field Work

The field results and reports indicate that as a whole the capture methodology proved effective and efficient. Conducting such work in the GIS environment was proven to not only be a viable option, but a highly efficient one in terms of promoting data accuracy and consistency, while limiting post-processing requirements and data import complexities. The live environment established across ArcGIS server and ArcGIS Online, shows how data can be captured and altered in the field while being accessible to monitoring and analysis applications. The following key observations have been made in aspects relating to the field capture process:

7.1.1. Mobile Device Selection

Several different mobile devices were used during field capture and exposed to the field environment for an extend period. Each worked effectively suggesting that any current generation smartphone makes an effective field capture device, in terms of GNSS accuracy requirements, general robustness and use, and ability to run capture software. The difficulties experienced with loss of GNSS signal, during mid-day and in certain mountainous areas, is a limitation that would potential only be overcome by using cost prohibitive survey grade devices. The GNSS signal loss can be attributed to a lack of dedicated satellite constellations covering South Africa, which will improve in future as more GNSS satellites are lunched.

7.1.2. Field Maps Application

The ease of integration into the ArcGIS environment offered by ArcGIS Field Maps is unparalleled, which makes it the most situatable field capture application. The simplicity and customisation of the application makes it universally applicable and adaptable without requiring redevelopment to allow changes to the forms or feature classes. ArcGIS Field Maps has a low bandwidth and computing resource requirement, which makes implementation accessibility high. Collection accuracy exceeded the WCG specifications, and the capture form provides self-explanatory capture and attribute addition procedures. Attaching images to features proved to be cumbersome due to the increased time required to save a captured point, however this can be attributed to poor mobile data connection. The inconstant mobile data connection posed the greatest threat to the operation, the Western Cape is not effectively covered, and the application offered no offline capture ability when connection was lost. This is however not due to the Field Maps application but rather the particular configuration required to function in the WCG domain. This presented the largest barrier to field workers that resorted to geotagged images to record feature locations in these situations. Since the conclusion of the project the WCG domain has been restructured to accommodate offline capture.

7.1.3. Field Work

The field work provided the required results and proved that the GIS environment and ArcGIS Field Maps can be an effective asset capture and field tool. The challenges experienced during field work provides insight into the need for a structured approach in planning and dedicated time management when capturing road assets. Further the importance of the contribution made by effective monitoring, through the Road Asset Management: Street/Traffic Light Poles Web Application, and access to all related data was also confirmed. Field work remains challenging and costly, despite the efficiency improvements capture devices and software offer. As such more consideration should be given to what attributes and data is collected, along with the core dataset, while the effort of field work is made. In this project the oversight to capture the bulb type and pole type of streetlights limited the level and precision of analyses that could be conducted. However, due to the data structure the streetlight dataset can always grow and improve, so enriching the dynamic streetlight repository.

7.1.4. Data Output

The data output from the Streetlight ArcGIS Field Maps Application, and associated manual capture and augmentation of the data, provided a working dataset that meets all the requirements initial set out for the WCG Streetlight repository. Based on the extent and quality of field work conducted, there was an opportunity for this dataset to be far richer in terms of attributes. This could be improved by better planning and scoping as referred to the above sections.

7.2 Streetlight Repository

The final datasets that constitute the streetlight repository, were derived from analysis of the field data and include:

- Streetlights Poles – which contains the locations of streetlight poles and various attributes associated from the nearest WCG road. This dataset also conations image attachments as captured per feature in the field.
- Traffic Lights – which contains the locations of individual robots and various attributes associated from the nearest WCG road. This dataset also conations image attachments as captured per feature in the field.
- Traffic Light Sets – which contains the centroid location of traffic light intersections and various attributes associated from the nearest WCG road.

The repository is housed in the WCG Roads SDE database, with feature layers published via ArcGIS Server to enable the Streetlight Web Application, as discussed in section 6.2.1 and documented in appendix 4. The web application's focus is to visually present and give context to the streetlight locations, while also facilitating various queries and searches on related road network and topographic data. Search functions have also been added to locate roadworks or active projects as-well-as bridges and culverts, enabling ease of orientation and context-based information for a given streetlight location.

The accessibility to data through the streetlight repository provides, both in terms of GIS and spatial data environment, and via the traditional database systems attribute table export, opportunity for internal monitoring and an effective discussion tool for operations planning. The suitability of the GIS based system and spatial repository not only lies in the advantages provide by web-based mapping and spatial queries, but also in the ability to be 'reduced' to table or paper-based information, which consultants and municipal maintenance teams are familiar with. It is this transversal integration in both systems and user's requirements that shows the success, sustainability and potential growth of the GIS data environment for WCG Road Directorate' asset management.

7.3 GIS Analysis to Inform Planning and Decision Making

GIS analysis of the field captured data consisted of three components, association of related attributes, streetlight analysis and road network analysis. Attribute association established a sound methodology for processing field data to be suitable for inclusion in the repository. Streetlight analysis focuses on investigating lighting characteristics of the WCG lighting infrastructure. The analysis considered the impacts of individual streetlights as a whole in terms of coverage and intensity. The road network analysis focuses on lighting characteristics of the WCG road network. Effectively, investigating the frequency of streetlights and level of illumination on the roads.

It is envisioned that these analyses deliver methods that are replicable and adaptable, and providing spatial results that inform decision makers and planers of the state off assets. While some of the results are purely spatial, several offer quantitative data outputs that can directly influence asset management at an analytical level. Even though the analysis was conducted with generic streetlight variables, the results clearing show the suitability and capability that GIS offers for WCG Roads asset management. The following sections elaborate on key observations made in terms of the various analyses.

7.3.1 Association by Spatial Joins

Attribute association took the form of a join analysis, based on road proximity, allowing for attributes from the WCG road network to be allocated to the appropriate streetlight features. While the result has not been audited and exhaustively validated, the method and operational variables proved sound, as all streetlights successfully joined to a road and no duplicates where reported. This success indicates the possible application of spatial joins, for other road related or structure related road assets, that required a spatially derived connection to share information. The resulting streetlight dataset, which makes up part of the WCG Streetlight Repository, lays the foundation for web-based mapping and interaction with the data, which in turn drives functional visual analysis at a project level. It also provides a platform for planning and discussion, that allows active engagement with streetlight data and related spatial data. Subsequent analysis (discussed in the latter) made use of spatial joins which can only be conducted in a GIS environment, reiterating the need to house road asset data in a GIS environment.

7.3.2 Light Analysis

The results for light coverage analysis provides a visual tool that has the ability to represent specific illumination characteristics (light pattern, bulb and fixture type). Similarly, the intensity analysis results provide this same ability with the added benefit of quantifying the result as a polygon dataset to be further analysed or used as fixed regions in design and planning. Both results showcase the ability to provide a spatial represent of the state of lighting along roads, intersections and structures, and the effects proposed designs may have. While these GIS analyses offer results that are useful at all scales, they are particularly applicable when assessing or investigating road segments or specific structures. This is the initial foundation for digital twin development.

Intersection coverage is a relatively simple analysis, evaluating the number of streetlights covering an intersection, but provides useful information both visually and quantitatively. It can indicate a simple priority list when tabulated but is empowered in the spatial context where the surrounding environment (road and natural) is shown, as is the case with most of spatial analysis results observed.

7.3.3 Road network Analysis

The results of density, quantity and illumination percentage are all quantitative outputs, either related to specific roads or sections of roads, represented as raster pixels in the case of density analysis. Despite being derived spatially, such quantitative data is useful for further investigation, as it aligns with the input requirements of traditional methods used in WCG roads management. However, as showcased in the former sections with the correct symbolisation, the data outputs can be presented in the GIS environment in a highly informative manner. The spatial data clearly presents which roads are highly populated or well illuminated by streetlights. Density rasters effectively show hot and cold spots of lighting and the distribution of lighting features, in more complicated road intersections. All while maintaining a presentation of reference data and the spatial context, which is only paralleled by design drawings in the context of the WCG Roads Directorate.

8 CONCLUSION AND RECOMMENDATIONS

8.1 Conclusion

Much of the road management work in the WCG Roads Directorate is defined by long term strategic development objectives and routine inspection and maintenance procedures. Yet a large part is needs based or reactive, as a result of changes in the natural environment (natural disasters or manmade), which are addressed through the vast engineering expertise within the directorate. However, to effectively plan, manage and execute road infrastructure initiatives, be it in terms of administrative tradition or plan-making, requires both expertise and comprehensive information (Masser & Ottens, 2019).

This study aimed to enhance the ability of existing expertise through the provision of a comprehensive streetlight dataset. The aim was to establish the extent and current state of streetlighting along the WCG road network and develop a comprehensive asset record within a GIS environment. The study further aimed to evaluate the effectiveness of GIS as a tool for capturing, analysing, and interrogating streetlight data, in an effort to produce actionable results related to density, extent, coverage, and alignment with related datasets.

A conclusive streetlight repository was visualised to represent the state of streetlighting, enabling strategic planning and resource optimisation. This study demonstrates that GIS and spatial data, in the context of the WCG Roads Directorate pertaining to streetlights, can effectively communicate the location characteristics and condition of road assets, while providing the spatial context required to establish relation to the WCG road network.

8.1.1 Comprehensive Streetlight Repository

This study has successfully addressed the foundational goals of developing a GIS-based capturing system and analysis tools, that inform planning and decision making. By creating an improved and verified spatial dataset of streetlight assets, the study has met its primary aim of producing a consolidated streetlight repository. Having a comprehensive streetlight repository, represents a significant step toward formalising and centralising all WCG road asset data, to improve infrastructure planning and management.

8.1.2 Data Capture and Verification

The data capture methods employed, including ArcGIS Field Maps, proved effective in simplifying the complexities of field data collection. By integrating GNSS data directly into the GIS environment, the system eliminated many technical challenges associated with non-integrated devices and systems. Despite technical limitations, such as intermittent offline functionality, the capture methodology demonstrated that field operations could be seamlessly incorporated into the GIS environment, laying the groundwork for more efficient data-driven workflows.

8.1.3 Streetlight Data Analysis and Visualisation

While the GIS analysis conducted as part of the study, offers only a proof-of-concept rather than definitive results due to the lack of true lighting characteristics, it does validate the potential of geospatial techniques to enhance decision-making processes. The ability to model spatial relationships, such as light coverage at intersections or along the road network, showcased the adaptability of GIS for both immediate analysis and long-term strategic planning. The integration of analysis tools with the repository has facilitated actionable insights, such as identifying areas for resource allocation base on lack of coverage or lack of intensity. This study also demonstrated the value of GIS for presenting both spatial streetlight data and analysis results in a visual and interactive format. The developed web application enabled users to query and contextualise streetlight locations, integrating related datasets such as active road projects, other road assets (bridges), and environmental data (imagery and topography). This holistic approach supports informed decision-making by providing a comprehensive view of streetlight infrastructure within its broader spatial context.

8.1.4 Relevance and Applicability of GIS

In alignment with literature that underscores the role of GIS in optimising infrastructure management, the results highlight GIS's ability to facilitate data-driven decision-making, asset visualisation, and strategic planning. The findings demonstrate the system's suitability for both short-term projects and long-term asset management, showcasing its adaptability to organisational needs and technical capabilities. Overall, the study provides a replicable model for GIS-based streetlight data capture and analysis that can inform infrastructure management processes. By addressing the challenges of incomplete data and integrating GIS capabilities into daily operations, this research establishes a strong foundation for future advancements in asset management and infrastructure optimisation leveraging spatial data.

8.2 Recommendations

The analysis conducted to demonstrate the capabilities of GIS in asset management and status reporting provides valuable insights but also highlights the need for refinement tailored to specific use cases and asset types. While the GIS analysis methodology can be adapted and enhanced over time, the real-world data capture process has yielded several actionable recommendations that should be carefully considered in future initiatives of this nature:

8.2.1 Recommendation 1: Streamlining Streetlight Data Capture Through Integrated Operations

The cost of maintaining the GIS infrastructure and training personnel can be significant, with field capture often being the greatest expense. To improve the efficiency and effectiveness of streetlight data capture, it is recommended that the process continue to be integrated into the daily operations of the WCG Roads GIS unit. However, adjustments are necessary to address the challenges identified during implementation.

The initial integration approach, while logical for leveraging existing workflows, proved insufficient due to the high volume of features and the time-intensive nature of individual fieldwork. To optimise efficiency, it is recommended to allocate additional resources, such as team-based field operations or enhanced planning tools, to manage the workload more effectively.

The road asset capture process remains a demanding task regardless of methodology or technology employed. Based on the extent and quality of field work conducted, there was an opportunity for this dataset to be far richer in terms of attributes. By better aligning with operational needs and anticipated needs, to providing richer datasets enhancing capabilities and information, the future burden of field work can be reduced and the value of work increased.

8.2.2 Recommendation 2: Ensuring Offline Functionality for Field Data Collection

To address the challenges of limited cellular network coverage in the Western Cape, it is strongly recommended that the system used for data collection be designed to support offline functionality. This capability would allow field workers to collect and edit data in areas without network coverage and sync their changes once they return to a connected area. The importance of disconnected editing has been highlighted both in the literature (e.g., Nielson, 2013) and through practical experience, where it has proven essential for the success of field work operations.

As outlined, the feature class used for data collection included versioning in the geodatabase and provides a system that is robust enough to function effectively in both connected and offline environments – but this must be supported by the greater IT infrastructure.

While the ability to capture data offline has subsequently been enabled in the WCG GIS environment, this initial limitation exposed a critical flaw in the reliance on constant cellular connectivity. Although live data updates are desirable for GIS integration, prioritising offline functionality would significantly improve the reliability and efficiency of data collection workflows, especially by negating the post processing of off platform data captured in areas with no connection.

8.2.3 Recommendation 3: Optimizing GNSS Accuracy for Streetlight Data Collection

To improve the consistency of GNSS accuracy during streetlight data collection, it is recommended to set a realistic accuracy requirement of up to 4 meters, balancing achievable precision with practical field conditions. Preliminary tests revealed that maintaining 3.5-meter accuracy was challenging, particularly during vehicle-based data collection.

As a mitigation measure, the number of GNSS observations should be increased from 2 to 5 epochs, allowing for averaged readings to enhance positional accuracy. While the 4-meter threshold was generally achievable, certain factors, such as reduced GNSS availability during midday in summer and in mountainous areas, posed difficulties. These environmental constraints should be accounted for in planning and scheduling of fieldwork to ensure optimal conditions for data capture.

By adopting a 4-meter accuracy standard, increasing the number of GNSS observations, and scheduling fieldwork to avoid periods of reduced satellite availability, the data collection process can be made more reliable and effective.

8.2.4 Recommendation 4: Leveraging Advanced Technologies for Streetlight Data Collection

To enhance the efficiency and frequency of data collection, it is recommended to adopt remote sensing data collection methods, such as drones and satellite high-resolution imagery. These tools can significantly reduce collection time while providing relatively precise and up-to-date data.

The use of remote sensing, specifically leveraging CoCT imagery to capture traffic lights, demonstrates the effectiveness for feature capture and should be expanded as a core method in data collection efforts. Integrating drones for aerial data capture can further complement this approach by offering flexible and localised data collection capabilities, particularly in areas where traditional fieldwork is time-intensive or logistically challenging.

8.2.5 Recommendation 5: Adoption GIS Analysis and GIS Tools

To enhance streetlight management and asset planning, it is recommended that the WCG Roads Directorate fully integrate GIS methodologies into their workflows. GIS should be standardised as the key platform for all road asset data, facilitating data integration across systems, and improving the understanding of the status of road assets and enabling dynamic visual analysis.

Additionally, prioritising the development of a digital twin framework for real-time monitoring in GIS and predictive maintenance, can further optimise asset management. Finally, refining the analysis methodologies through pilot projects and improving the visual outputs for stakeholder engagement will enhance the effectiveness of these tools for long-term planning and resource allocation.

8.2.6 Recommendation 6: Future Research on the Correlation of Accidents and Streetlighting Using GIS Data and Analysis

The Western Cape Government Roads Infrastructure Directorate maintains a record of accident data. Incident recording under law enforcement is globally known to be lacking, in the particular case of the WCG, location-based data is seldomly in an easily interpreted format (Pain, et al., 2006). Since 2021 the WCG Accident Data unit has introduced a workflow that identifies and attributes, where possible, an incident's geographic coordinate. Accident data thus presents an opportunity for interpretation and analysis through GIS, which thus far has not been realised. Literature generally suggests that there is a benefit to streetlighting in terms of reducing night-time accidents and incidents of crime (Rea, et al., 2009). However, the quantity of spatially referenced accident date was not deemed sufficient, at the time of conducting this study, to investigate any correlation between accidents and streetlighting.

It is recommended that future research utilise the authoritative streetlight data repository established in this study to analyse the potential relationship between streetlight locations and accident locations and/or hotspots. Understanding such spatial relationships can prove valuable in decision making and resources allocation to streetlighting, in an effort, to improve road safety.

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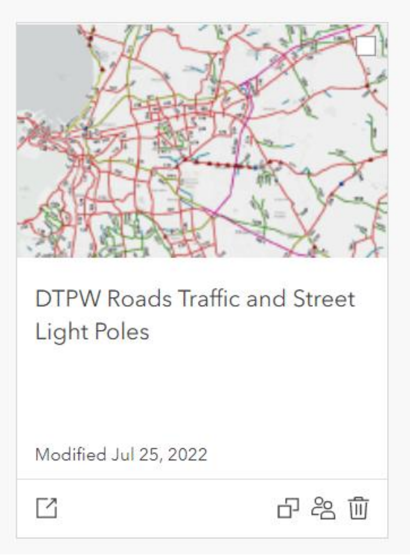
Appendices

Appendix 1: DTPW Road Traffic and Street Light Poles



Feature classes

Two feature classes were created capture the streetlight and traffic light poles

Name

TransGIS_AGOL.LDR.Light_Pole

Fields		
Display Name	Field Name	Type
OBJECTID	OBJECTID	ObjectID
Pole_ID	Pole_ID	String
GlobalID	GlobalID	GlobalID
Photos And Files	Photos And Files	Attachment

Name

TransGIS_AGOL.LDR.Traffic_Light_Pole

Fields		
Display Name	Field Name	Type
OBJECTID	OBJECTID	ObjectID
Pole_ID	Pole_ID	String
GlobalID	GlobalID	GlobalID
Photos And Files	Photos And Files	Attachment

Feature classes used for base data

Published feature services (rest endpoints)

The feature classes above were published in 2 feature services and secured.

DTPW/DTPW_Roads_FieldMaps_Light_Pole (FeatureServer)

DTPW/DTPW_Roads_FieldMaps_Traffic_Light_Pole (FeatureServer)

Published mapping service (rest endpoint)

Also included was a map service containing the following base layers.

DTPW/DTPW_Roads_FieldMaps_BaseData (MapServer)

Standard DTPW symbology was used for the provincial road network, traffic and street light poles.

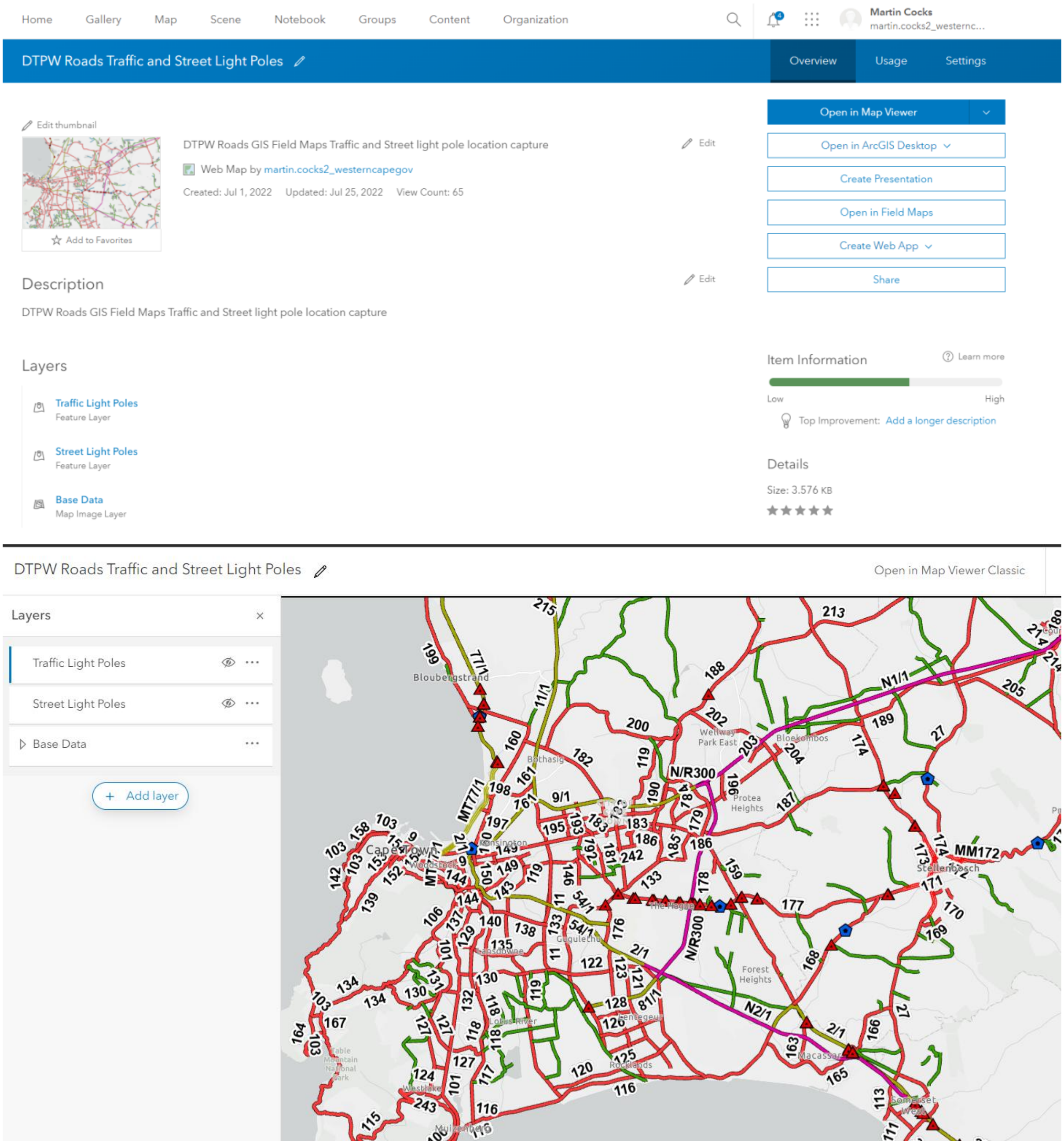
ArcGIS Online feature layers

The feature and map services were added to ArcGIS Online as the following feature layers

- DTPW Roads FieldMaps Street Light Pole Locations
- DTPW Roads FieldMaps Traffic Light Pole Locations
- DTPW Roads FieldMaps Base Data

ArcGIS Online map settings

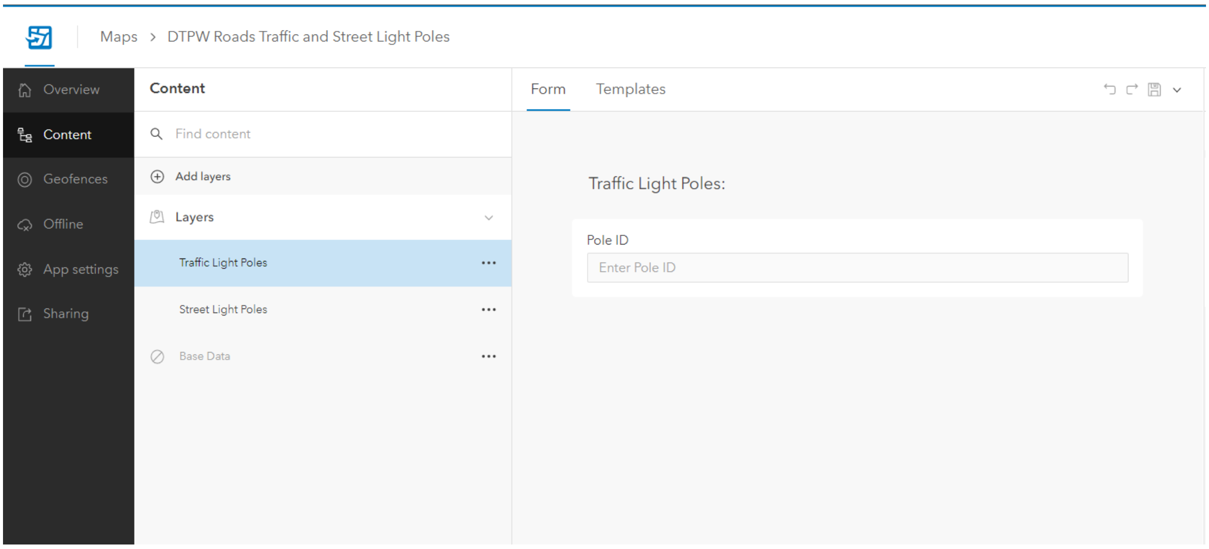
The two feature layers and mapping service were included in an ArcGIS Online map called *DTPW Roads Traffic and Street Light Poles*


Home
Gallery
Map
Scene
Notebook
Groups
Content
Organization
Martin Cocks
martin.cocks2_westernc...
DTPW Roads Traffic and Street Light Poles
Overview
Usage
Settings
Edit thumbnail
Add to Favorites
DTPW Roads GIS Field Maps Traffic and Street light pole location capture
Edit
Web Map by martin.cocks2_westerncapegov
Created: Jul 1, 2022 Updated: Jul 25, 2022 View Count: 65
Open in Map Viewer
Open in ArcGIS Desktop
Create Presentation
Open in Field Maps
Create Web App
Share
Description
DTPW Roads GIS Field Maps Traffic and Street light pole location capture
Layers
Traffic Light Poles
Feature Layer
Street Light Poles
Feature Layer
Base Data
Map Image Layer
Item Information
Learn more
Low
High
Top Improvement: Add a longer description
Details
Size: 3.576 KB
DTPW Roads Traffic and Street Light Poles
Open in Map Viewer Classic
Layers
Traffic Light Poles
Street Light Poles
Base Data
Add layer
N1/1
N2/1
N/R300
MM172
Bloubergstrand
Cape Town
Protea Heights
Forest Heights
Stellenbosch
Macassar

ArcGIS Field Maps application settings

Form settings

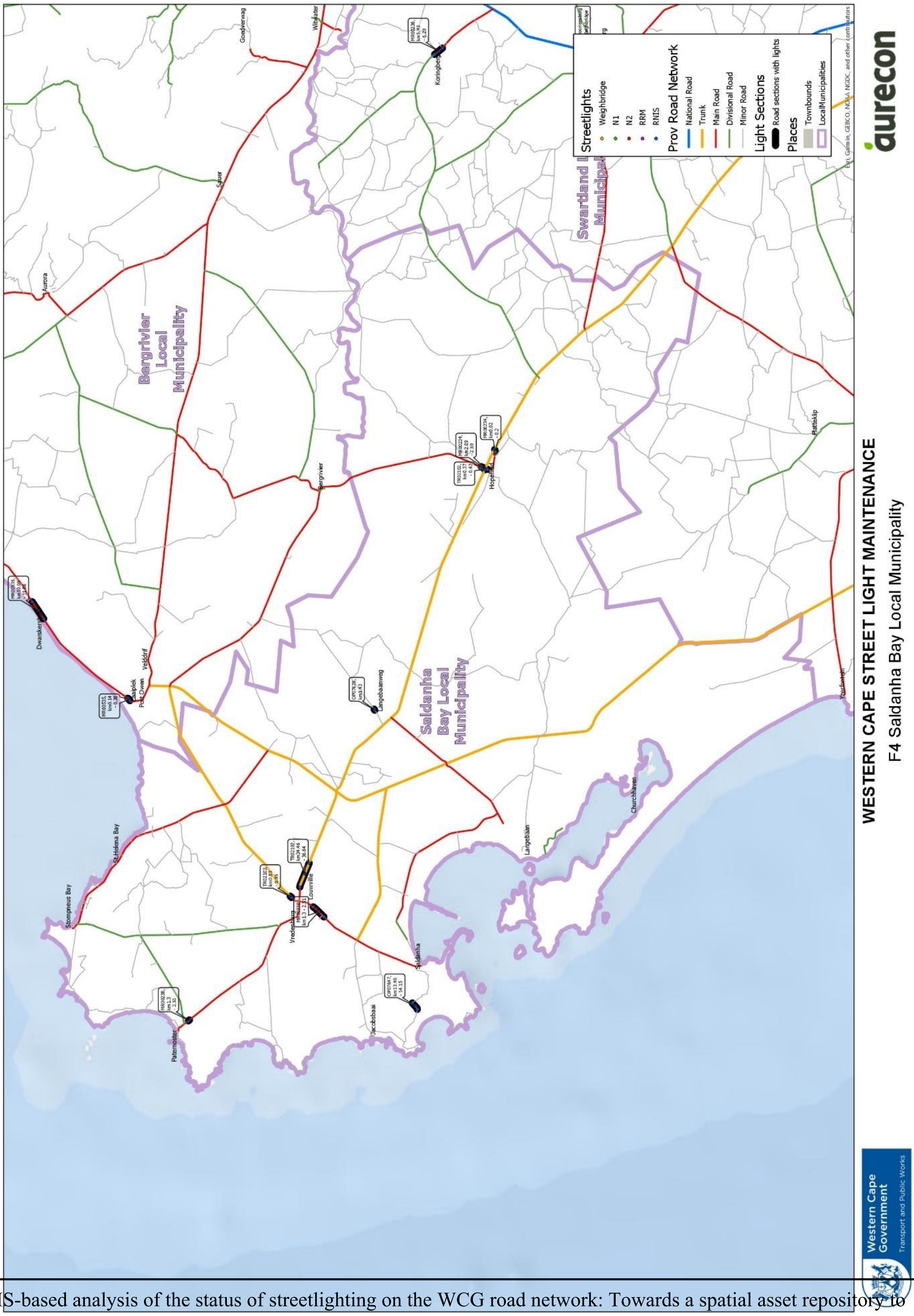
The editing form was configured in the same way for both editable layers



Other field map settings

- Offline: Off
- Collection accuracy: 4m
- GPS averaging: On
- Photo size: Medium
- Snapping: Off
- Streaming: Off
- Edit Multiple: Off

Appendix 2: Street Light Source: Saldanha Bay Maintenance



A GIS-based analysis of the status of streetlighting on the WCG road network: Towards a spatial asset repository to guide decision making and asset management (13613)
Jason P. Truter (South Africa)

FIG Congress 2026
The Future We Want - The SDGs and Beyond
Cape Town, South Africa, 24–29 May 2026

Appendix 3: Street Light Capture Field Reports

Streetlight Capture Report:	Nov - Dec 2022	

Below is an extract of Towns completed in these months and comment on findings. Priority areas made up the focus of areas after completing the West Coast LM. The web map in the GIS portal allows for real time quantitative tracking despite variation between infield conditions and desktop data.

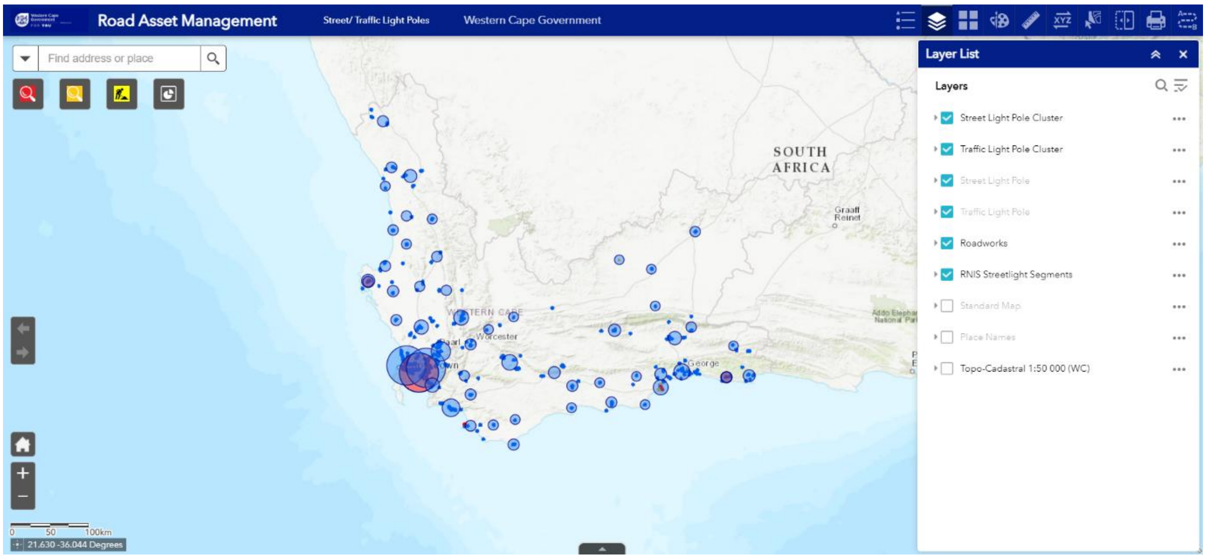
These months' fieldwork has shown consistency in streetlights per section length, but access is still mix between walking and vehicle-based capture. The City of Cape Town areas proved to be walking based and hazardous both in terms of personal and vehicular safety and as such require additional time and consideration to capture successfully and safely. Satellite and solar conditions have caused GPS accuracy drop below the required several times a day and the intensification of loadshedding have also affected the data signal required to capture, necessitating a flexible capture location schedule. The West Coast DM Towns are isolated and often require walking to capture segments. Streetlights are not consistent and are sometimes obscured requiring additional effort to find and access.

Immediate future work will consist of a mix of City of Cape Town and remaining Cape Winelands, with the N2 in Cape Town and greater Paarl and parts of the Wellington making up several long sections but requiring low travel time. These two DM's constitute a substantial coverage of all segments with Garden Route being the only other DM with extensive number of segments.

Date	Town	Complete	District Municipality	Comments
2022/11/29	Doringbaai	Yes	West Coast	These towns presented mostly wooden pole streetlights. Accessibility was good only requiring walking a few sections.
2022/11/29	Strandfontein	Yes	West Coast	
2022/11/29	Vredendal	Yes	West Coast	
2022/11/30	Uitkyk	Yes	West Coast	These towns presented a mixture of cement wooden pole streetlights. Accessibility was
2022/11/30	Ebenhaeser	Yes	West Coast	
2022/11/30	Rietpoort	Yes	West Coast	
2022/11/30	Bitterfontein	Yes	West Coast	

				poor requiring walking most sections.
2022/12/01	Vanrhynsdorp	Yes	West Coast	These towns presented a mix of wooden and cement pole streetlights. Accessibility was good only requiring walking a few sections.
2022/12/01	Klawer	Yes	West Coast	
2022/12/12	N7 (N1 to Morning Star)	Yes (revisit off ramp)	CCT	All steel poles with labels, mostly requiring walking and with up to three segments per road section made the capture very time consuming. Accessibility very difficult due to pole placement and traffic. GPS and data problems due to solar and loadshedding caused additional delays.
2022/12/13	N7 (N1 to Morning Star)	Yes	CCT	
2022/12/14	N7 (N1 to Morning Star)	Yes	CCT	
2022/12/15	N7 (N1 to Morning Star)	Yes	CCT	
2022/12/19	N1 (N7 to R300)	Yes (revisit off ramp)	CCT	All steel poles with labels, mostly requiring walking and with up to three segments per road section made the capture very time consuming. Accessibility very difficult due to pole placement and traffic. GPS and data problems due to solar and loadshedding caused additional delays.
2022/12/20	N1 (N7 to R300)	Yes	CCT	
2022/12/21	N1 (N7 to R300)	Yes	CCT	
2022/12/22	N1 (N7 to R300)	Yes	CCT	

Appendix 4: Web Application Asset Management – Street/Traffic Lights



Street and Traffic Light Pole Web Application

Purpose

Road network Management application adapted for road and road furniture asset management. To identify locations of street and traffic lights belonging to the department.

Content

Vector Services

- Street Light Pole Cluster
- Traffic Light Pole Cluster
- Street Light Pole
- Traffic Light Pole
- Roadworks
- RNIS Streetlight Segments
- Standard Map
- Place Names

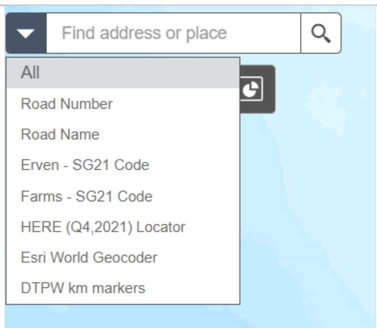
Raster Services

- Topo-Cadastral 1:50 000 (WC)
- World Topographic Map

Functionality

Search Layers

The Asset Management – Street/Traffic Lights Web Application includes the following layers in the search:

Road Number *7-character format*	**Road Name** Full name or letters constituting the name of a road.	
DTPW km markers		
Esri World Geocoder • Default in every map. • Allows the user to search for an address in South Africa.	**Erven – SG21 Code**	
	Farms – SG21 Code	
	HERE (Q4, 2021) Locator	

Queries

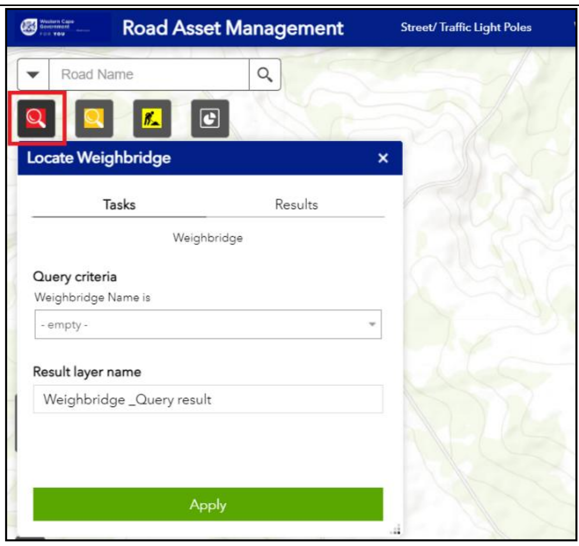
The Asset Management – Street/Traffic Lights Web Application includes the following query options:

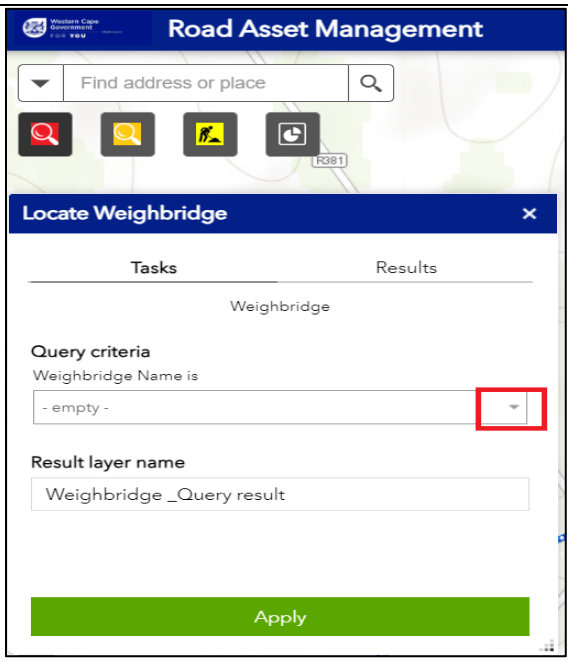
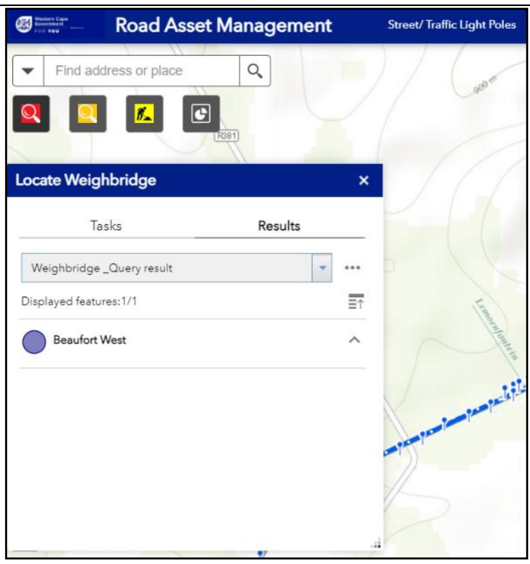
1. Additional Functionality within the query results is accessible by clicking the 3 dots on the right-hand side of the results page. 2. The options allow the user to: a. Zoom to b. Pan to c. Flash d. Statistics e. View in Attribute Table f. Remove of the result	

Locate Weighbridge

This query is based on a list of the unique values for the selected field in the layer. The user can interactively select the weighbridge name from a drop-down list of options.

Locate Weighbridge Query Example

1. Select the Locate Weighbridge Query (1st Query on the left)	

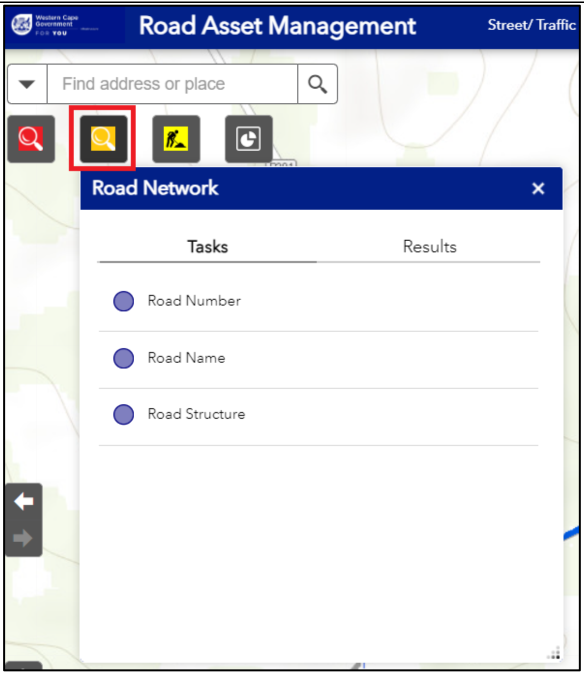
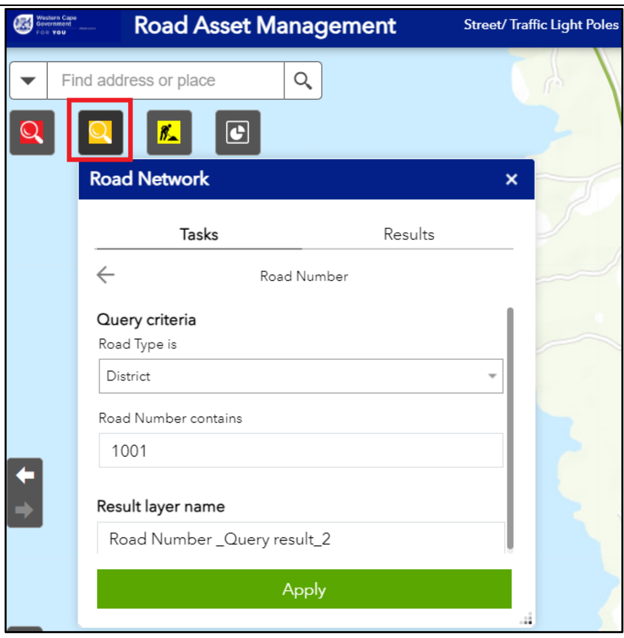
2. Click the drop-down arrow and select weighbridge from the listed options. 3. Click **Apply**.	
4. The results will look similar to the following:	

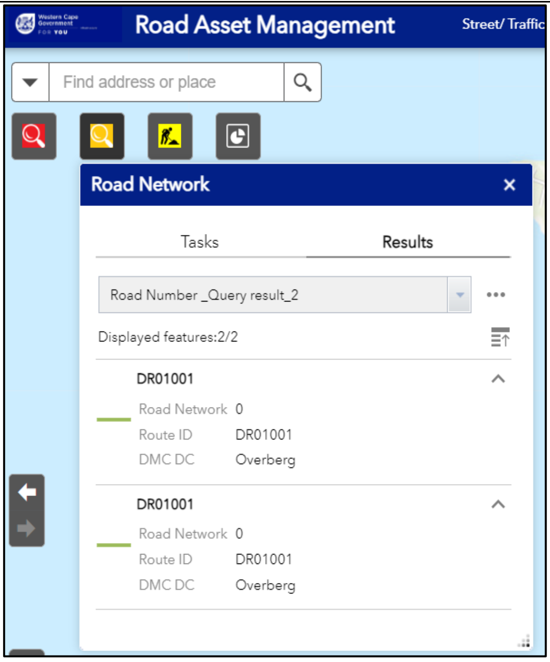
Road network

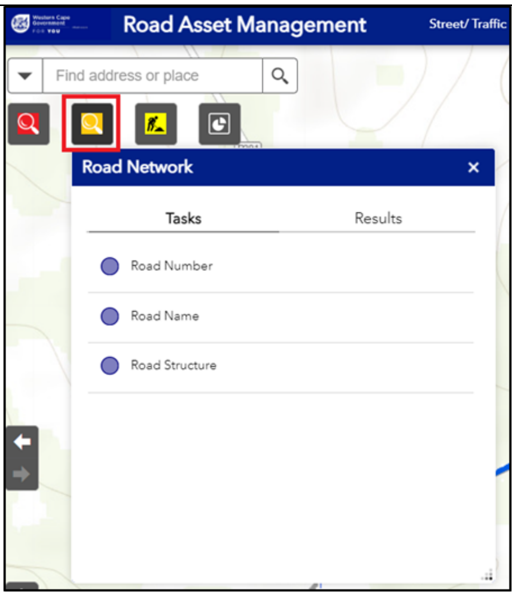
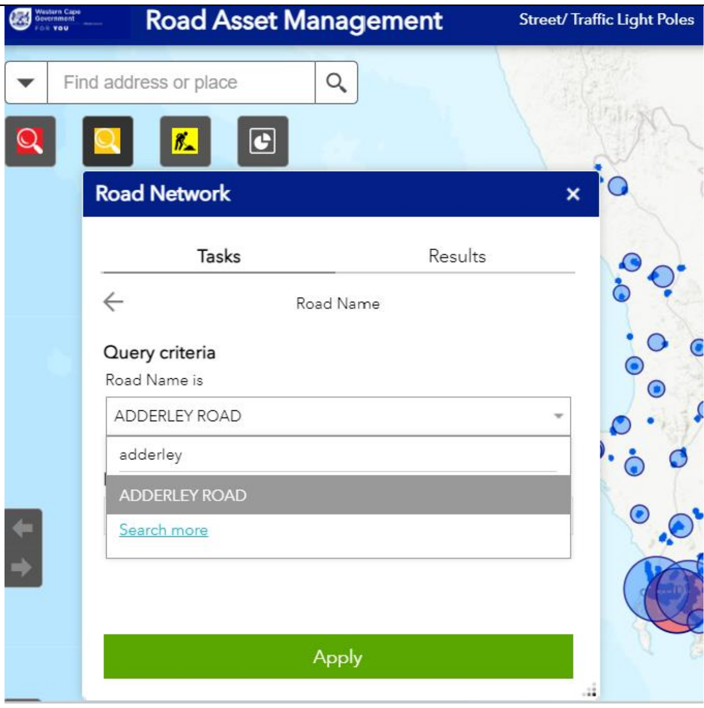
This query contains three sets of tasks

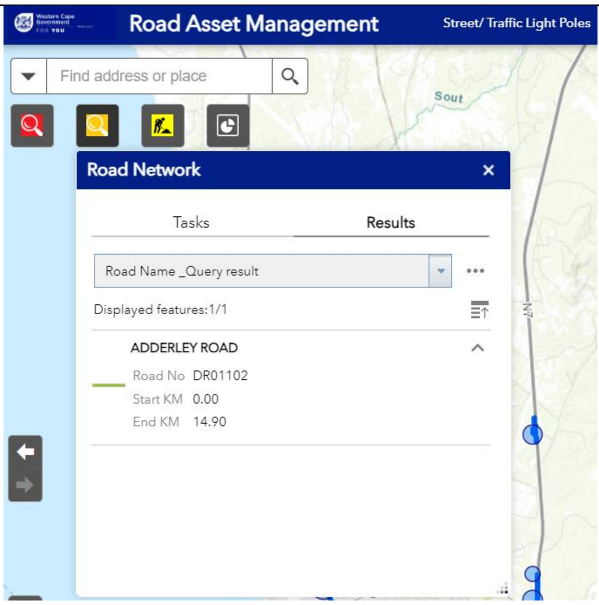
Road Number	Road Name	Road Structure
This query requires the input of: • **Road Type or** • **Road Number**	This query requires the input of: • **Road Name**	This query requires the input of: • **Structure Number** • **Description**

		• **Type Code**

Road Number 1. Select the Road network Query (2nd Query on the left) 2. Select the Road Number Task	
3. Enter the following information: • **Road Type** field, for example *'District'*. • **Road Number** field, for example *'1001'*. 4. Select **Apply**.	

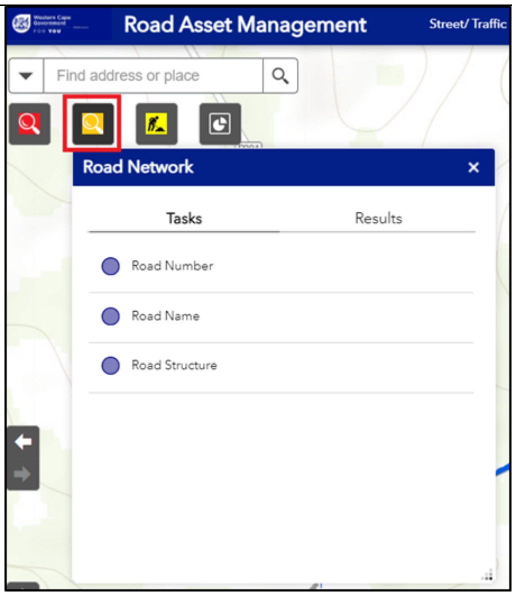
5. The results will look similar to the following:	

Road Name 6. Select the Road network Query (2nd Query on the left) 7. Select the Road Name Task	
8. Enter the following information: • **Road Name** field, use the drop-down arrow to select road from list or type road name in search dialog box: for example, *'Adderley Road'*. 9. Select **Apply**.	

10. The results will look similar to the following:	

<table>
<tr>
<td>
Road Structure

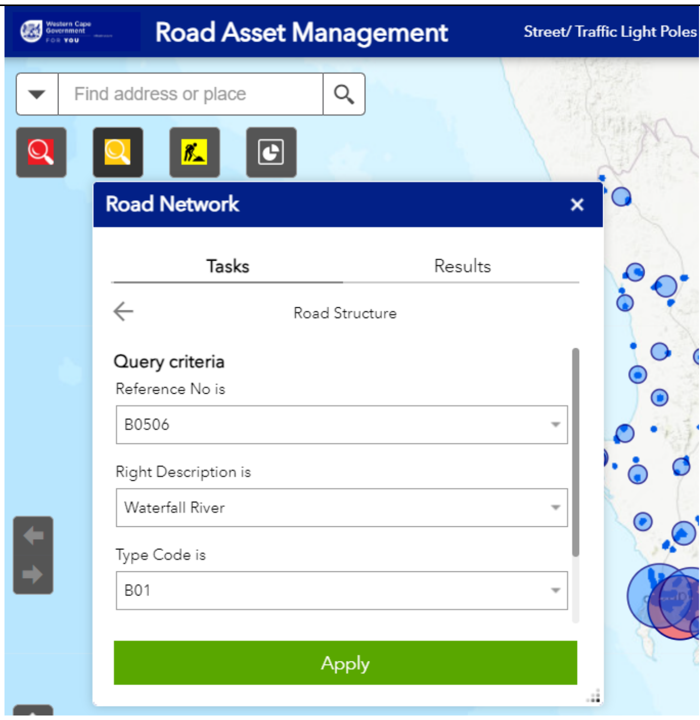
Select the Road network Query (2nd Query on the left)
Select the Road Structure Task

</td>
<td>


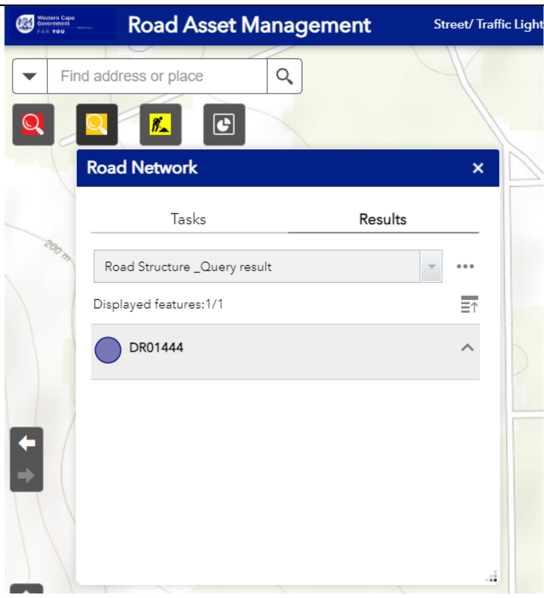
</td>
</tr>
<tr>
<td>
<ol start="3">
Enter the following information:

Reference No. field, for example 'B0506'.
Right Description field, for example 'Waterfall River'.
Type Code field, for example 'B01'.

Select Apply

</td>
<td>


</td>
</tr>
</table>

5. The results will look similar to the following:	

Locate Roadworks

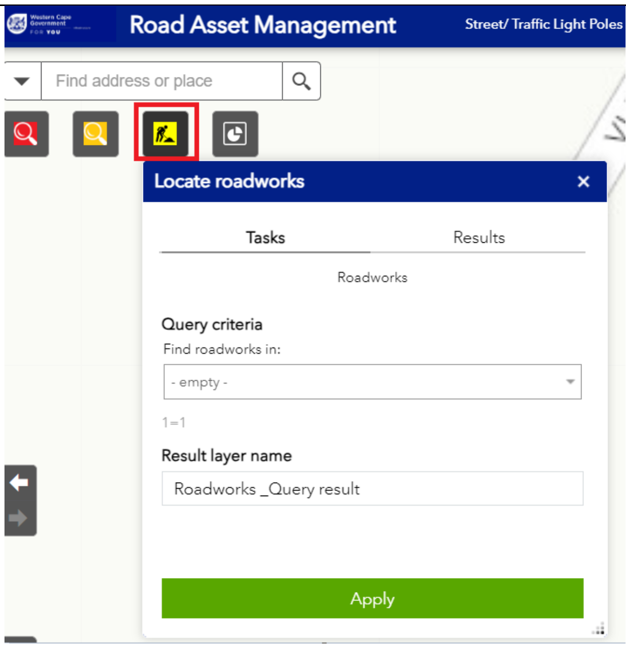
The query locates identified areas of active roadworks that affected the capture of street and traffic lights. The query functionality is based on a list of the unique values for the selected field in the layer. The user can use the drop-down functionality to see the list of regions with active roadworks and interactively select the roadworks by region from the drop-down.

<table>
<tr>
<td>

Locate roadworks

11. Select the Locate roadworks Query (2nd Query to the right)

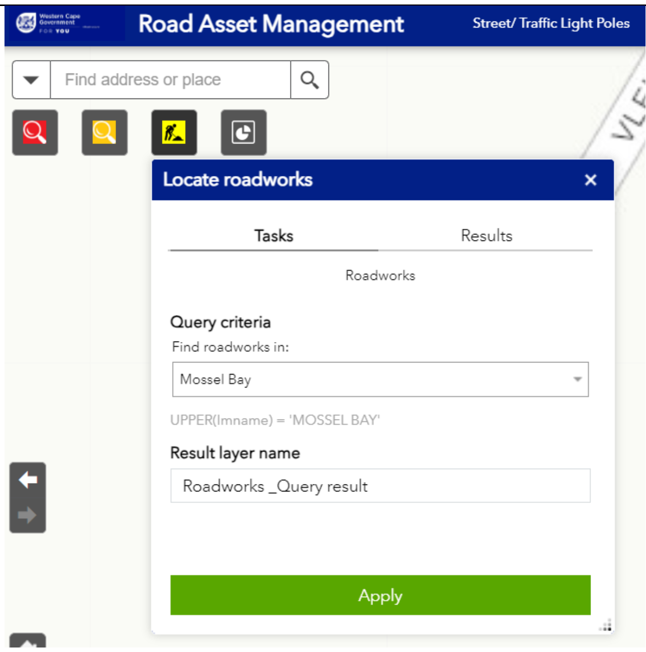
</td>
<td>



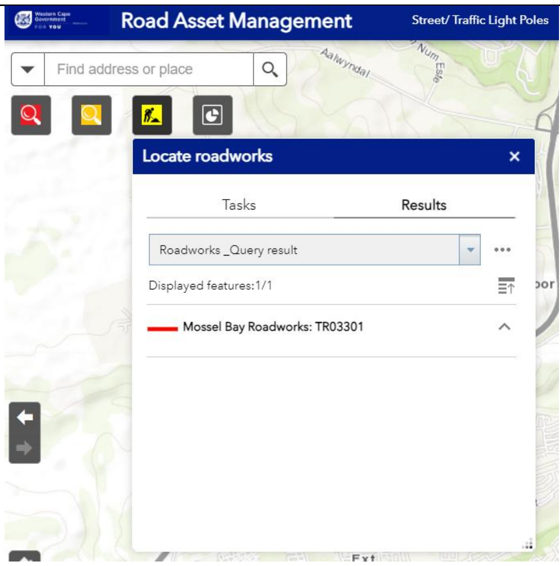
</td>
</tr>
<tr>
<td>

12. Enter the following information:
    - **Find roadworks in:** for example *'Mossel Bay'*.
13. Select **Apply**.

</td>
<td>

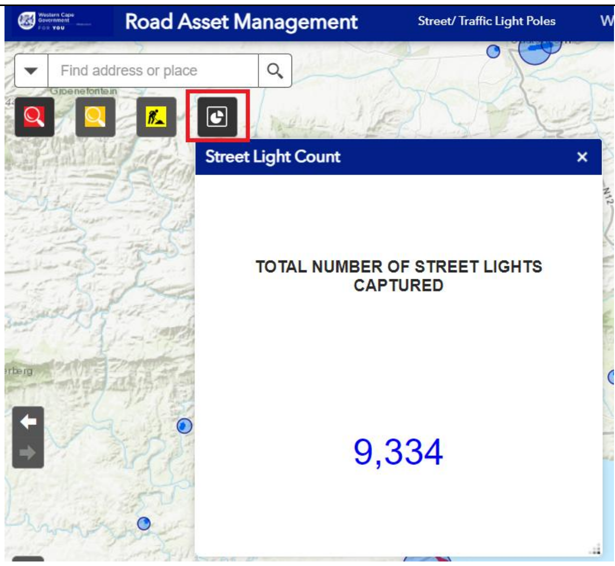


</td>
</tr>
</table>

14. The results will look similar to the following:	

Infographic

The widget uses feature count statistics to calculate and display the total number of streetlights captured for the project.

Street Light Count 15. Select the Street Light Count Infographic widget (1st widget on the left) 16. The widget displays the total number of streetlights captured for the province.	

Appendix 5: Ethics Pre-screening Report

UNIVERSITY OF CAPE TOWN
IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD

PRE-SCREENING QUESTIONNAIRE OUTCOME LETTER

STU-EBE-2024-PSQ001422

2025/01/15

Dear Jason Truter,

Your Ethics pre-screening questionnaire (PSQ) has been evaluated by your departmental ethics representative. Based on the information supplied in your PSQ, it has been determined that you do not need to make a full ethics application for the research project in question.

You may proceed with your research project titled:

A GIS-based investigation of the state and level of street-lighting on the Western Cape Government Road Network

Please note that should aspect(s) of your current project change, you should submit a new PSQ in order to determine whether the changed aspects increase the ethical risks of your project. It may be the case that project changes could require a full ethics application and review process.

Regards,

Faculty Research Ethics Committee