# A Short Course on Nautical Charts and Basic Plotting
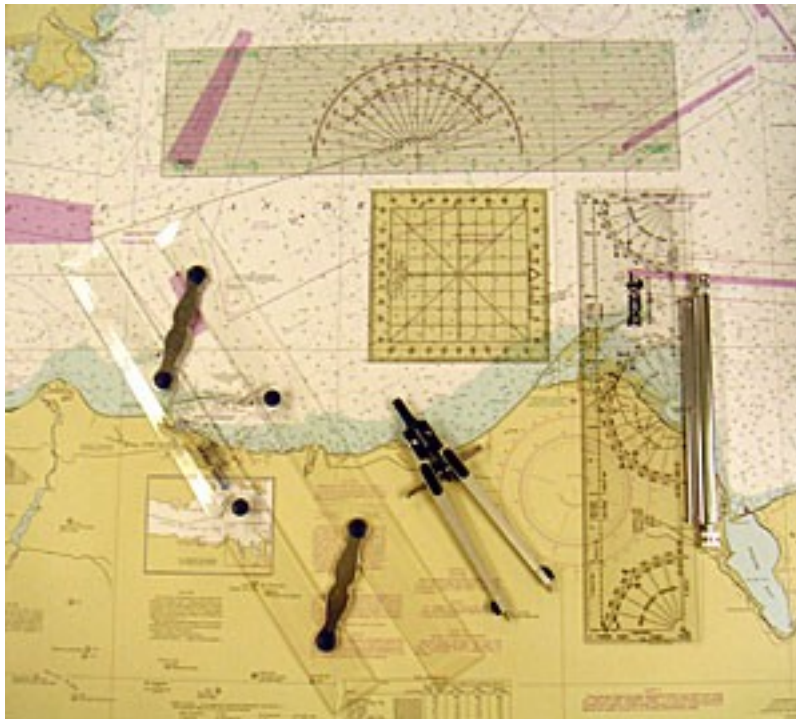## For the Recreational Boater

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# Introduction

This manual is intended for the recreational boater who wants to understand the elements of the nautical charts that we employ to learn how to navigate through a body of water, the wealth of additional information available about our waterways, and how to perform basic navigation and plotting tasks. The motivation for me to write this is simple – as a recreational, then commercial, boater myself, I came to realize that while reading a chart does not appear to be all that difficult, there were many items of information that I had not realized were even there, either because I did not use that information for my boating excursions or because the charts that I commonly use did not contain certain elements of information. Prior to taking a course to acquire my captain's license, I knew nothing about the Coast Pilot® or Light List, sources of an incredible amount of information of interest to masters of a vessel of any size. In addition, the general books to which recreational boaters are often directed are excellent in many ways but rarely tackle the subject of even simple plotting.

This manual is divided into three parts. Part 1 describes the navigation resources available to the recreational – and commercial – mariner. This section describes places where one can acquire charts. As importantly, it also discusses where reference materials can be obtained that can help a mariner interpret the markings on the charts and provide additional, from the meaning of aids to navigation and the period of a lighthouse light to the composition of the seabed and height of a bridge to where fuel and public anchorages can be found.

Part 2 introduces nautical charts from the perspective of a recreational mariner. This section covers the basics of latitude and longitude, aids to navigation, and the contents of a nautical chart. The general information in this part of the manual applies to any nautical chart anywhere, although the focus is on United States. Most of the specific examples are from Lake Champlain (New York and Vermont) because these were my home waters until 2014; now they are the Halifax River, Atlantic Ocean off of Ponce de Leon Inlet, and the northern Indian River and Mosquito River Lagoon (Florida).

Part 3 of the manual describes basic navigation and plotting. This section starts with an explanation of the relationship between magnetic north (as shown on a compass), true north (as shown on a chart), and ship's north (i.e., as shown on your vessel's compass), and introduces the concepts of variance and deviation. That is followed by a description of the instruments that are needed in order to plot courses on nautical charts. The bulk of the chapter describes a number of rudimentary plotting problems and how to solve them, such as determining position by dead reckoning, estimating time of arrival, finding your position with lines of position, and compensating for current and other environmental factors when plotting a course.

The focus of this document is on printed charts as well as reading and plotting using hand tools. Marine electronics make a lot of these tasks automatic, but I have always taken the posture that people need to know the basic process behind what our automated and computer-based

tools are telling us. In that spirit, I offer this tutorial. Hopefully, readers will be inspired to read some of the more excellent, in-depth texts referenced at the end of this paper.

*Suggestions, corrections, and/or any other comments about this manual are welcome.*

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# Part 1: Nautical Charts and Other Resources

This section presents an introduction to nautical charts. In addition, supplementary resource materials that can aid in the interpretation of the symbols on the chart and yield a better understanding of the coastal and navigational features depicted on the charts will also be introduced.

## 1.1. Purpose and Role of Nautical Charts

Nautical charts are not just the "roadmap" of waterways but so much more. On a street map, pretty much all you get are the streets; maybe you will also see identifiers for some buildings, parks, and other structures, but you won't find a listing of all of the traffic signals and the duration of a red and green light. And streets, of course, highly regulate where you can operate your vehicle; if on a two-way road, for example, you drive on the right side (at least, in the U.S.).

Lakes and oceans are a little less organized. In some areas, there are nautical traffic lanes, but boat movement is not so restricted on the vast majority of the waterways. If you are more than a couple of miles away from land, knowing the landmarks and structures can help you orient yourself to your position. Navigational aids of all types help you find your way or keep out of danger.

Charts show significantly more information than a street map. Charts describe not only where the water is but also the characteristics of the waterway and seabed. They show the shape of the coast, location of islands and hazards, navigation markers, warnings of hazards, the height of bridges and other obstructions, and offer much more information.

Nautical charts are an essential item on board any vessel, even small recreational boats that do not wander very far from land. Unexpected events from weather to current can take you a bit further than you intended to go, and the charts can help you get to where you want to be or to a port of refuge.

### 1.1.1. Types of Charts

The National Oceanic and Atmospheric Agency (NOAA) produces U.S. nautical charts. Charts are generally categorized by their scale; large-scale charts show a lot of detail over a small geographic area, while small-scale charts show a lesser amount of detail over a large area. In general, then, mariners would use small-scale charts when on the open seas going from one place to another and would use the largest scale possible for navigating inland and near-shore.

NOAA uses the following chart classifications:[1]

- *Sailing charts* have a scale of 1:600,000 and smaller. These charts are for determining

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[1] From *U.S. Coast Pilot®*.

position along the coast when approaching from the open ocean or for sailing between distant coastwise ports.

- *General charts* have a scale between 1:150,000 and 1:600,000. These charts are primarily for coastal navigation outside of near-coastal reefs and shoals.
- *Coast charts* have a scale between 1:50,000 and 1:150,000. These charts are for inshore navigation leading to sizeable bays and harbors, and for navigating large inland waterways.
- *Harbor charts* have a scale larger than 1:50,000 and are for navigating harbors, anchorage areas, and smaller waterways.

*1.1.2. Obtaining Charts*

There are a variety of sources from where nautical charts can be obtained. Most boaters buy a chart for local waters at a local marine store. Charts for just about any part of the world can be obtained from any number of sources online.

The official NOAA site for U.S. charts is the Office of Coast Survey Web site.[2] Links from that page will assist you in obtaining paper charts, electronic charts, publications with additional information, and historical charts. This site also lists a number of retailers that sell NOAA charts.
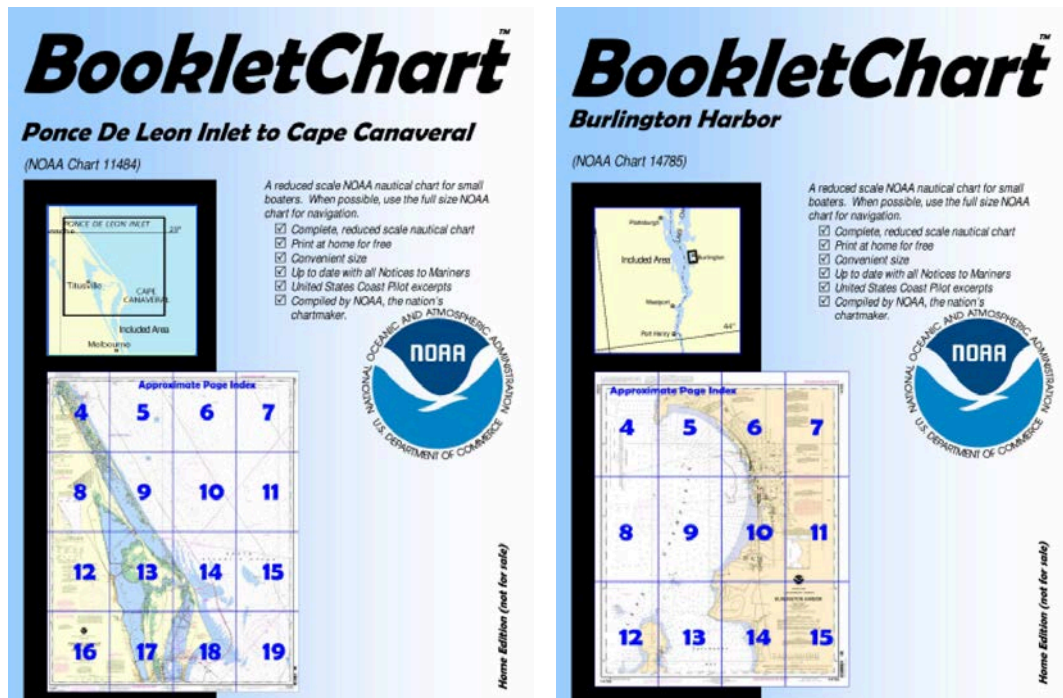


**Figure 1.1.** NOAA Booklet Charts 11484 (Ponce De Leon Inlet to Cape Canaveral) and 14785 (Burlington Harbor)*.*

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[2] http://www.nauticalcharts.noaa.gov/

NOAA has charts available in a number of formats, including:

- *Print on demand (POD)* charts are printed upon request and shipped to the customer. These charts are generally very up-to-date, including updates that might be as recent as the week before printing.
- *Booklet charts* are downloadable charts in PDF format that can be printed for free (Figure 1.1).[3]
- *ChartViewer* allows all NOAA charts to be viewed online.
- *Electronic charts* are downloadable charts for use with commercial software. Downloads are available as Raster Navigational Charts (NOAA RNC®) in .BSB format for raster display systems or as Electronic Navigational Charts (NOAA ENC®) for electronic charting systems. Neither of these formats is designed for printing. Electronic charts are constantly updated. PDF format is also available.[4]

Although this paper will not discuss Geographical Positioning Systems (GPS) in any detail, there are a number of inexpensive apps available for laptop computers, mobile devices, and tablets for which one can download many national and international charts (Figure 1.2).
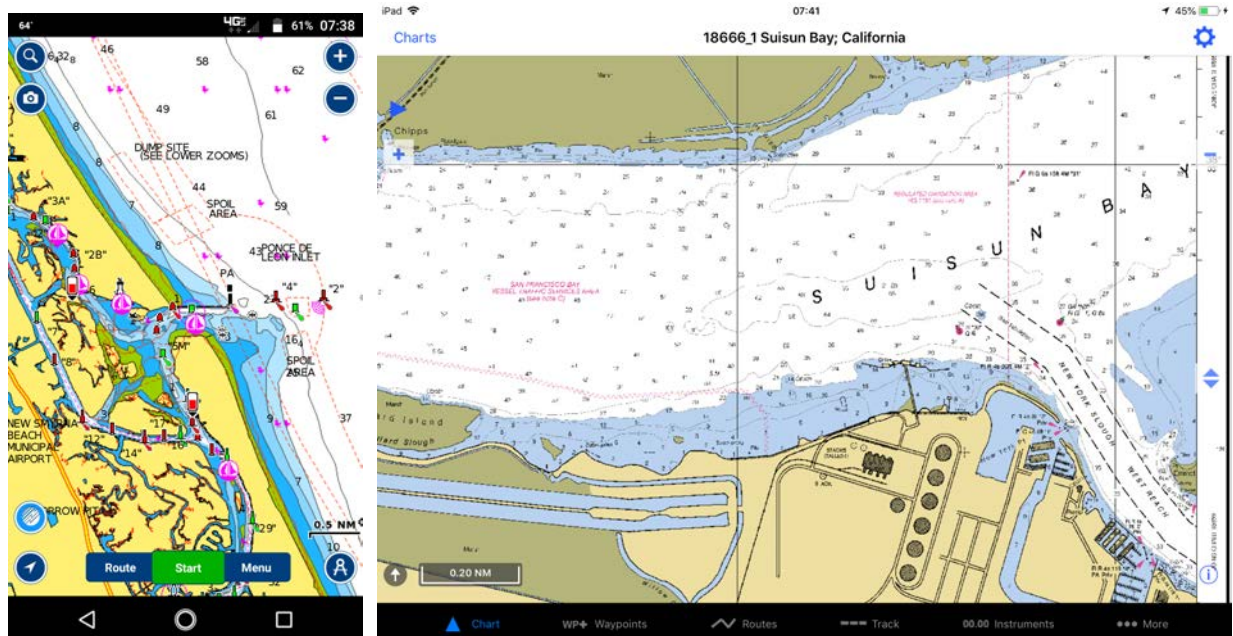


**Figure 1.2.** Screenshots of Navionics Boating HD (left, Android) and iNavX (right, iOS).

A technology related to GPS is the Automatic Identification System (AIS). AIS provides situational awareness for boaters. Vessels broadcast their position, speed, heading, and other information, and boats with an AIS receiver can see where other vessels are and respond accordingly. Most recreational boats fall below the legal requirement to use AIS, but boaters

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[3] Most of the chart fragment examples in this document come from booklet charts.
[4] https://www.charts.noaa.gov/InteractiveCatalog/nrnc.shtml

can build inexpensive AIS receivers.[5] OpenCPN (Figure 1.3), for example, is free, open source software[6] that can be used on a variety of operating system platforms for this purpose.
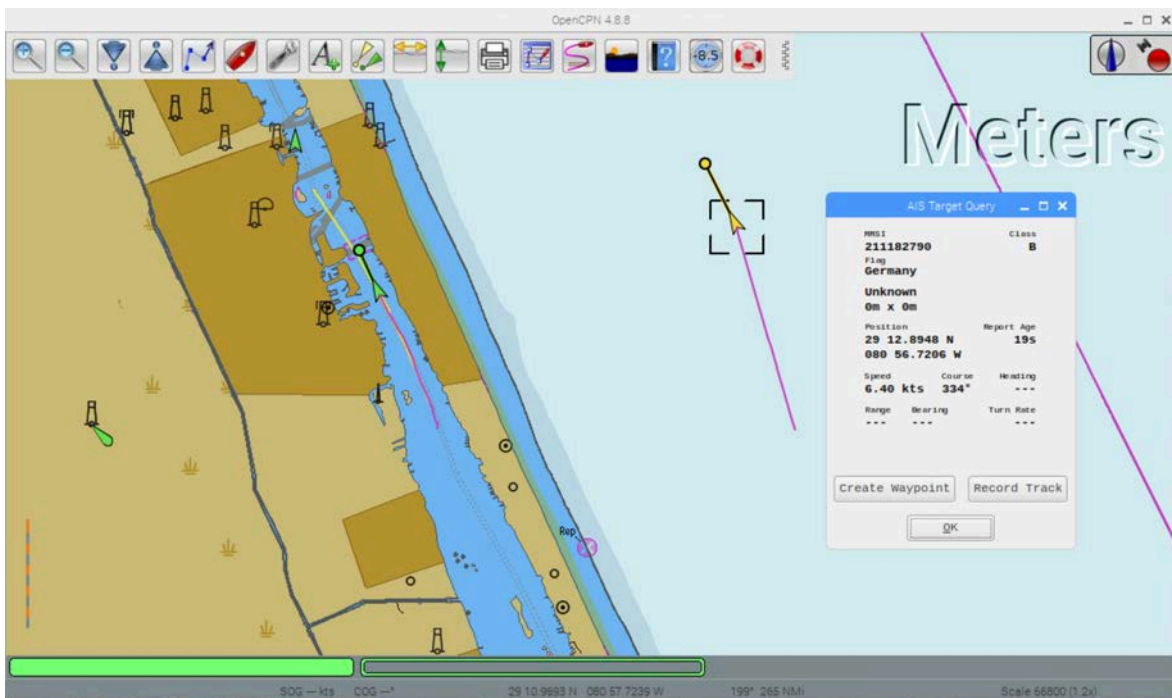


**Figure 1.3.** Screenshot of OpenCPN (Mac OS).

## 1.2. Supplementary Resources

Nautical charts are the graphical representation of the waterways and coastal zones. Like all graphical representations, they are filled with symbols that might seem arcane to the untrained eye. In any case, it is impossible for the diagrams to have complete information. For that reason, there are a number of documents that provide important information that supplements the charts.

### 1.2.1. Chart No. 1

The single best reference with which to understand the symbols and markings on U.S. nautical charts is a document called *Chart No. 1: Symbols, Abbreviations and Terms used on Paper and Electronic Navigational Charts* (Figure 1.4). Prepared by NOAA and the National Geospatial-Intelligence Agency (NGA), *Chart No. 1* can be downloaded from the NOAA Web site.[7]

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[5] https://www.garykessler.net/library/ais_pi.html

[6] https://opencpn.org/

[7] https://nauticalcharts.noaa.gov/publications/docs/us-chart-1/ChartNo1.pdf
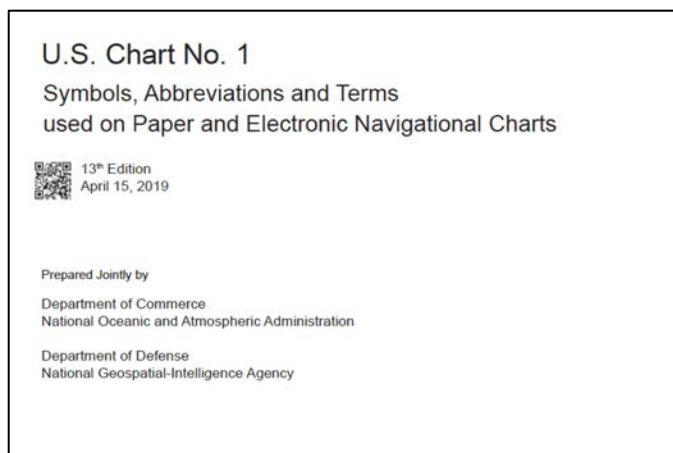
**Figure 1.4.** *Chart No. 1: Symbols, Abbreviations and Terms used on Paper and Electronic Navigational Charts.*

*Chart No. 1* is divided into five sections:

- *Introduction:* General introduction to the document, and an overview of the symbols and information that can be found on a nautical chart.
- *General:* Symbols and information related to chart identification, distance, directions, and the compass.
- *Topography*: Chart symbols related to features found on land.
- *Hydrography:* Chart symbols related to features related to the water and seabed.
- *Navigation Aids and Services:* Chart symbols related to aids to navigation. Sections P (Lights) and Q (Buoys, Beacons) provide information on the lateral system of navigation buoys used worldwide (although, of course, there are two systems in different regions of the globe, making this particularly useful if you will operate a vessel outside of your normal boating zone).

*1.2.2. U.S. Coast Pilot®*

The *United States Coast Pilot®* supplements nautical charts by providing detailed information about coastal features that would be impossible to include on a chart. Published by the National Ocean Service, *U.S. Coast Pilot®* documents can be downloaded from the NOAA Web site.[8]

The *U.S. Coast Pilot®* is a series of nine documents (Figure 1.5), each covering a different region of the United States:

**Atlantic Coast Regions**
1. Eastport, Maine to Cape Cod, Massachusetts
2. Cape Cod, Massachusetts to Sandy Hook, New Jersey

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[8] https://nauticalcharts.noaa.gov/publications/coast-pilot/index.html

3. Sandy Hook, New Jersey to Cape Henry, Virginia
4. Cape Henry, Virginia to Key West, Florida
5. Gulf of Mexico, Puerto Rico, and U.S. Virgin Islands

**Great Lakes Region**
6. Great Lakes and Connecting Waterways

**Pacific Coast Regions**
7. California, Oregon, Washington, Hawaii, and Pacific Islands
8. Alaska - Dixon Entrance to Cape Spencer
9. Alaska - Cape Spencer to Beaufort Sea
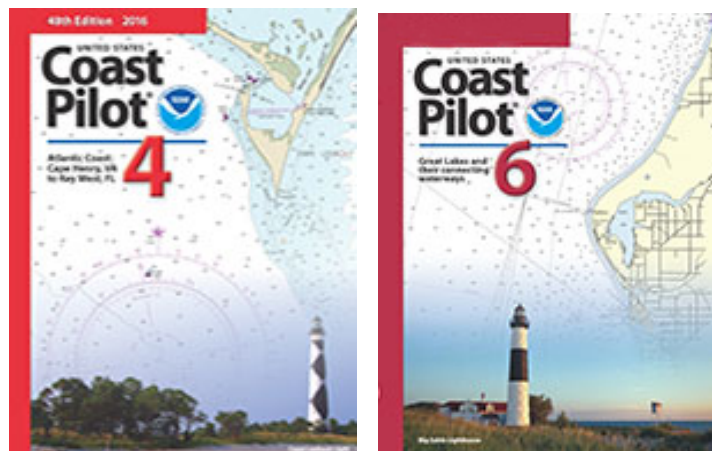
**Figure 1.5.** *U.S. Coast Pilot®* (Regions 4 and 6).

Each Coast Pilot has the same general layout. Chapter 1 is titled General Information and is a wealth of information about how to use the Coast Pilot, the meaning of various terms, generic information about nautical charts, notices to mariners, aids to navigation, communication and assistance procedures when in distress, radio usage, pollution regulations, and much more;[9] this chapter alone is extraordinarily valuable even in the absence of the rest of the document. Chapter 2 is titled Navigation Regulations and covers various rules and regulations affecting navigation in the jurisdictions covered by this particular document.

Each subsequent chapter covers a part of the region; the Region 6 Coast Pilot, for example, has 12 additional chapters covering the Great Lakes, St. Lawrence River, Lake Champlain, and the connecting waterways. Each chapter identifies the pertinent navigational charts that cover the region and provides detailed descriptions of pertinent landmarks, waterways, and other reference points useful for navigation. Anchorage areas, special harbor regulations, U.S. Coast Guard facilities, small-craft facilities, and other generally useful information is also provided.

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[9] There is also a section titled *Mineclearing: Caution*.

*1.2.3. USCG Light List*

The *U.S. Coast Guard Light List* describes lights, buoys, beacons, sound signals, and other aids to navigation found in the United States, both private and those maintained by the Coast Guard. The light list provides detailed information about the aids to navigation that could not fit onto the nautical chart itself. A chart, for example, might show a lighthouse but the *Light List* will contain additional information such as the latitude and longitude, seasonal variations, and other commentary. Published by the U.S. Government Printing Office, *Light List* documents can be downloaded from the U.S. Coast Guard Navigation Center Light List Web site.[10]
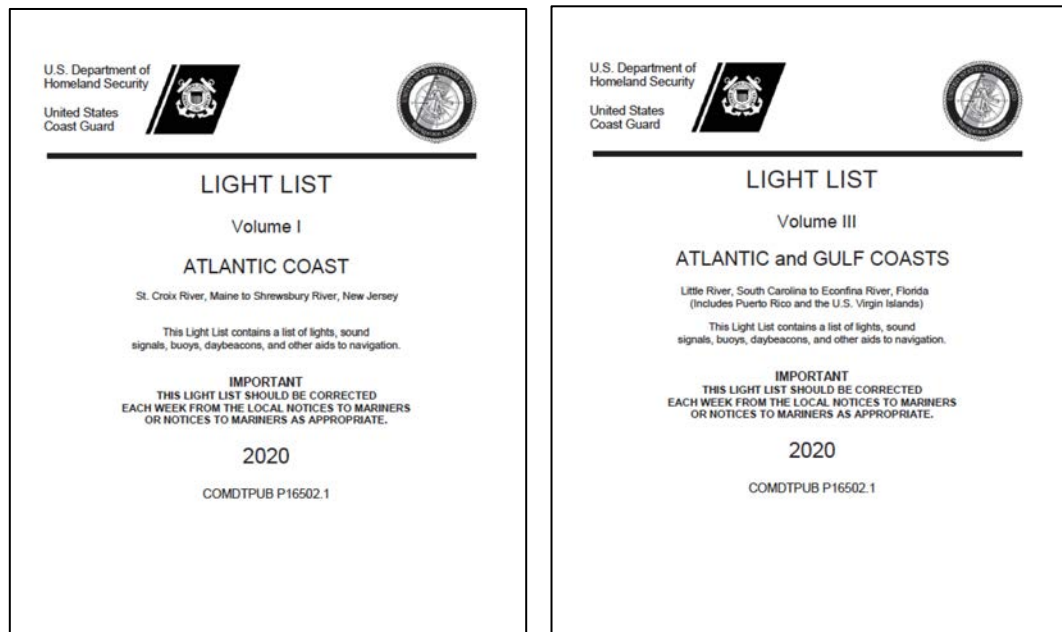


**Figure 1.6.** *Light List (Volume I: Atlantic Coast* and *Volume III: Atlantic and Gulf Coasts).*

The Light Lists are a series of seven volumes (Figure 1.6) covering the following geographic regions:

    I.   Atlantic Coast: St. Croix River, Maine to Shrewsbury River, New Jersey
   II.   Atlantic Coast: Shrewsbury River, New Jersey to Little River, South Carolina
  III.   Atlantic and Gulf Coasts: Little River, South Carolina to Econfina River, Florida (including Puerto Rico and the U.S. Virgin Islands)
  IV.   Gulf of Mexico: Econfina River, Florida to Rio Grande, Texas
   V.   Western Rivers: Mississippi River System
  VI.   Pacific Coast and Pacific Islands
 VII.   Great Lakes: Great Lakes and the St. Lawrence River above the St. Regis River

Each Light List has the same general layout. The beginning of the document includes an excellent overview of the lateral navigation system including examples of the markers as seen

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[10] http://www.navcen.uscg.gov/?pageName=lightlists

during the day and during the night, as well as those used on the Intracoastal Waterway and the western rivers. This is followed by a table that aids the mariner in determining the distance from which a light can be seen based upon its stated nominal range and actual visibility conditions. A description of aids to navigation and a glossary of terms precede the list of lights. Lights are listed in a numerical order that is used by the index.

Updates to the light list are issued by periodic Notice to Mariners and documents on the Light List Web site.

*1.2.4. Notice to Mariners*

Neither the charts, *Coast Pilot®*, nor *Light List* are totally error-free. Furthermore, many of the features and items on those documents change over time; a storm, for example, might knock down a structure on the land or cause an underwater wreck to shift position, or an unlighted buoy might be replaced with a lighted one. In any case, information contained in any of these published references can change over time.
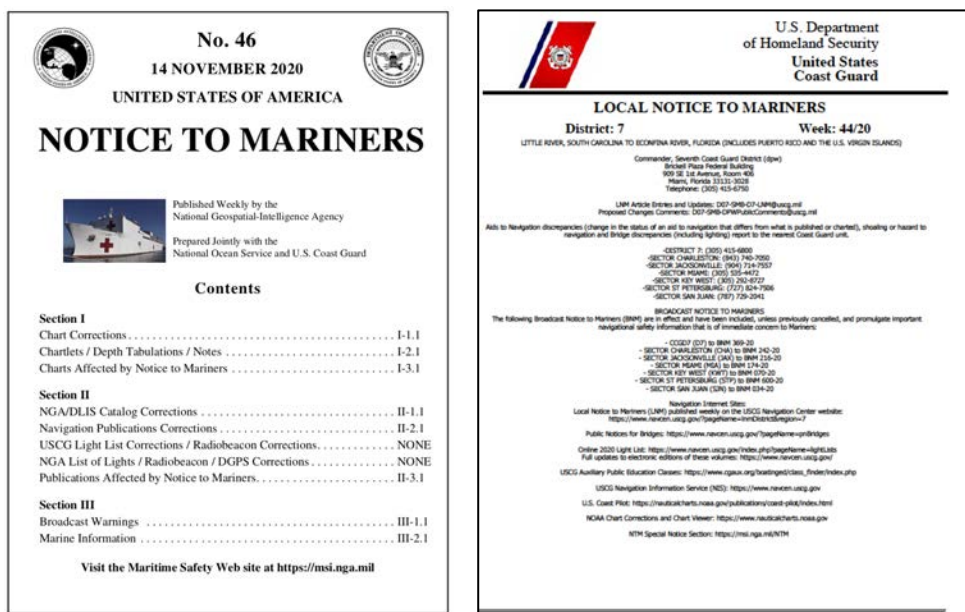


**Figure 1.7.** *Notice to Mariners* (No. 46 for the week ending 14 November 2020) and *Local Notice to Mariners* (44th week of 2020, first week of  November , USCG District 7).

Two series of documents provide updates to these publications. The *Notice to Mariners (NTM)* is published weekly by the NGA in cooperation with the National Ocean Service and USCG (Figure 1.7, left). By design, the NTM documents only provide chart corrections pertinent to ocean-going vessels. NTM documents can be downloaded from the NGA's Notice to Mariners Web page.[11]

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[11] https://msi.nga.mil/NTM

*Local Notice to Mariners (LNM)* documents provide weekly updates to charts and other publications (Figure 1.7, right). Distributed by the USCG Navigation Center Web site,[12] LNMs are organized by USCG district.

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[12] http://www.navcen.uscg.gov/?pageName=lnmMain

# Part 2: Nautical Charts

This section presents an introduction to reading and interpreting nautical charts. First, we will review the concepts of latitude and longitude, as well as the rules conveyed by the aids to navigation (ATON) system. Next will be an overview of the elements of a nautical chart, followed by several specific examples of chart features and symbols.

## 2.1. Latitude and Longitude

In order to read a chart – and, of course, in order to do any plotting on a chart – one must be familiar with latitude and longitude (Figure 2.1). Lines of *latitude* run east-west and are the reference with which to indicate position on the globe in the north-south direction. Because lines of latitude drawn on the globe appears as concentric circles, a line of latitude is also referred to as a *parallel*. Latitude is measured as a number between 0° and 90°, where 0° is the Equator, 90° north (N) is the North Pole, and 90° south (S) is the South Pole. In some cases, a "+" or "-" sign precedes the value; positive latitudes (+) are in the northern hemisphere and negative latitudes (-) refer to the southern hemisphere.
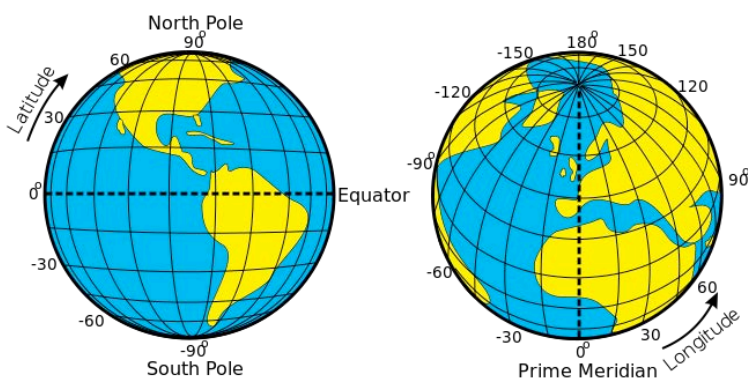


**Figure 2.1.** Latitude and longitude.[13]

Lines of *longitude* run north-south and are the reference with which to measure position on the globe in the east-west direction. Lines of longitude drawn on the globe appear like the sectional lines of an orange, coming together at the north and south poles. A line of longitude is also referred to as a *meridian* and can take on a value between 0° and 180°; 0° is the Prime Meridian and runs through the Royal Observatory in Greenwich (London) and 180° is the International Date Line. In some cases, a "+" or "-" sign precedes the value instead of an east (E) or west (W) designation; positive longitudes (+) are in the eastern hemisphere and negative longitudes (-) refer to the western hemisphere.

Almost all nautical charts are oriented so that geographic (true) north is towards the top. The vertical lines are the meridians (longitude) and the markings on the left and right border measure latitude. The horizontal lines are the parallels (latitude) and the markings on the top

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and bottom border measure longitude. *Note that the latitude and longitude scales are not the same.*

Latitude and longitude are measured in degrees (°), minutes ('), and seconds ("). A *degree* is composed of 60 *minutes*, which, in turn, comprises 60 *seconds*. The traditional nomenclature is to express latitude and longitude in a *degree, minute, second* (DMS) format, sometimes denoted *DD°MM'SS"*. The scales on the chart make it easy to find degrees, minutes, and tenths of minutes, so chart-based positions are usually denoted using a *DD°MM.MM'* format. Some GPS and other devices use a decimal notion, where latitude and longitude are written in whole degrees while minutes and seconds are expressed as a fraction of a degree, sometimes denoted *DD.DDD°*. As an example, the latitude and longitude of the wreck of the *O.J. Walker* in Burlington Harbor (Vermont) could be written as:

- 44°28'43"N, 073°14'26"W in DMS notation
- 44°28.72'N, 073°14.43'W in GPS or chart notation
- 44.479°N, 073.241°W in decimal notation

Appendix A describes how to convert between these three notations.

## 2.2. Introduction to Aids To Navigation

One of the primary reasons that mariners use a chart is to find – and stay within – navigable channels. An aid to navigation is any device external to the boat that helps a mariner find safe passage on the water. ATONs include buoys, lights, range marks, beacons, and other maritime indicators, as well as buildings and other features on land. Before examining the elements of, and symbols on, a chart, it is worth briefly reviewing the basic channel markers that a boater is going to see on the water. Understanding the ATONs and how they are interpreted will help the chart make sense.
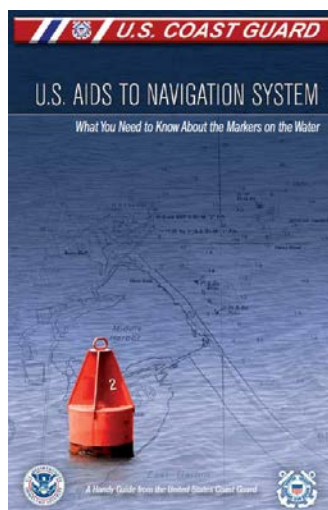


**Figure 2.2.** *U.S. Aids to Navigation* (USCG, 2011).

The marking system of navigational aids is defined by the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA)[14]. The system is well-defined and is quite logical to those who understand it; it is just a bunch of colored things on the water to those who do not. While the system itself is very consistent, it can appear confusing to those who do not know why certain colors are used in certain places.  This section contains a description of the aids to navigation as a high-level introduction and, also, as an indicator of why additional training and experience is required to fully understand the ATONs.

Most boaters in the U.S. are familiar with the mnemonic device *red right returning* as a reminder to keep the red buoys to the right of the boat when returning from sea. This rule is only correct in the IALA "B" system used in the western hemisphere and a few countries in Asia; the rest of the world uses the IALA "A" system which uses the opposite colorings.[15] One of the best references to the marker system in the United States is the U.S. Coast Guard's *U.S. Aids to Navigation System[16]* (Figure 2.2).

Under the IALA "B" system, "red, right, returning" means that red markers are on the right of the boat when returning from sea or when going from a larger to smaller body of water (e.g., from a lake into a bay or from a river into a channel leading to a marina). Red and green channel markers always have a number; red markers are even and green markers are odd. Furthermore, the only markers that have a number are the red and green channel markers. The numbers are merely for identification on a chart and do not convey any additional meaning (except for markers on Western Rivers, as noted below).

There are two variations to the "red, right, returning" rule in the U.S. The first variation is on the Intracoastal Waterway (ICW). The ICW is an inland waterway along the Atlantic Ocean and Gulf of Mexico, running roughly from Boston, Massachusetts to Brownsville, Texas. On the ICW, red markers are on the right as you traverse around the country in a clockwise direction (i.e., red on your right as you proceed south on the Atlantic coast and on your right as you proceed west on the Gulf coast). One way to remember this orientation is that red (the "hot" color) is towards the interior or landside while green (the "cool" color) is towards the open water.

The second variation is the Western Rivers Marking System rules that apply on the Mississippi River, tributaries above Baton Rouge, Louisiana, and other western rivers. In this system, red markers are to the right as you proceed upstream. Furthermore, numbers on ATONs on these waters are mile markers.

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[14] http://www.iala-aism.org/
[15] The IALA "A" system mnemonic is to match colors when returning from sea; i.e., green buoy on the right to match the boat's green light and red buoy on the left to match the boat's red light.
[16] http://www.uscgboating.org/images/486.PDF

**Figure 2.3.** Green (can) and red (nun) buoys. [Photos by the author.]



**Figure 2.4.** Red triangular and green square dayboards. (Note the yellow square and light at the top of the post on #47. [Photos by the author.]

There are two general types of channel markers, namely, floating and fixed. Floating ATONs are *buoys* (Figure 2.3), the most common of which are green *can* (square) and red *nun* (pointy-topped) shapes. For obvious reasons, buoy positions on a chart are approximate. ATONs that are attached to a fixed point on the Earth – called *beacons* – usually employ a post or piling at a known latitude and longitude. Beacons have a red triangle or green square *dayboard* with a number (Figure 2.4). Any fixed ATON with a light is simply referred to as a *light* and can include lit beacons (as in the figure) or a lighthouse (on a rock or land).

On the ICW, beacons and buoys have a yellow triangle or square; in general, a yellow triangle is on a red marker and a yellow square on a green marker.[17]

### 2.3. The Anatomy of a Nautical Chart

As stated earlier, nautical charts are the graphical representation of waterways and the nearby coast. Nearly everyone who owns or operates a boat has referred to a chart at least once in order to obtain a rudimentary understanding of the overall layout of the land and water. Charts

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[17] There are times when the ICW crosses a waterway marked according to the IALA lateral system. Although the day markers on the ICW are generally red with a yellow triangle and green with a yellow square, one might see a yellow triangle on a green can buoy or a yellow square on a red nun buoy when the ICW crosses a lateral system-marked channel. In those cases, the shape of the yellow symbol prevails as the ICW channel marker regardless of the color of the buoy (i.e., the yellow triangles mark the mainland side of the ICW even if on a green buoy).

also contain a wealth of information, including aids to navigation, landmarks, hazards, fishing areas, attractions, anchorages, etc. Recreational boaters use the same chart as commercial ships, so the information contained on the charts has to suffice for the biggest of vessels.
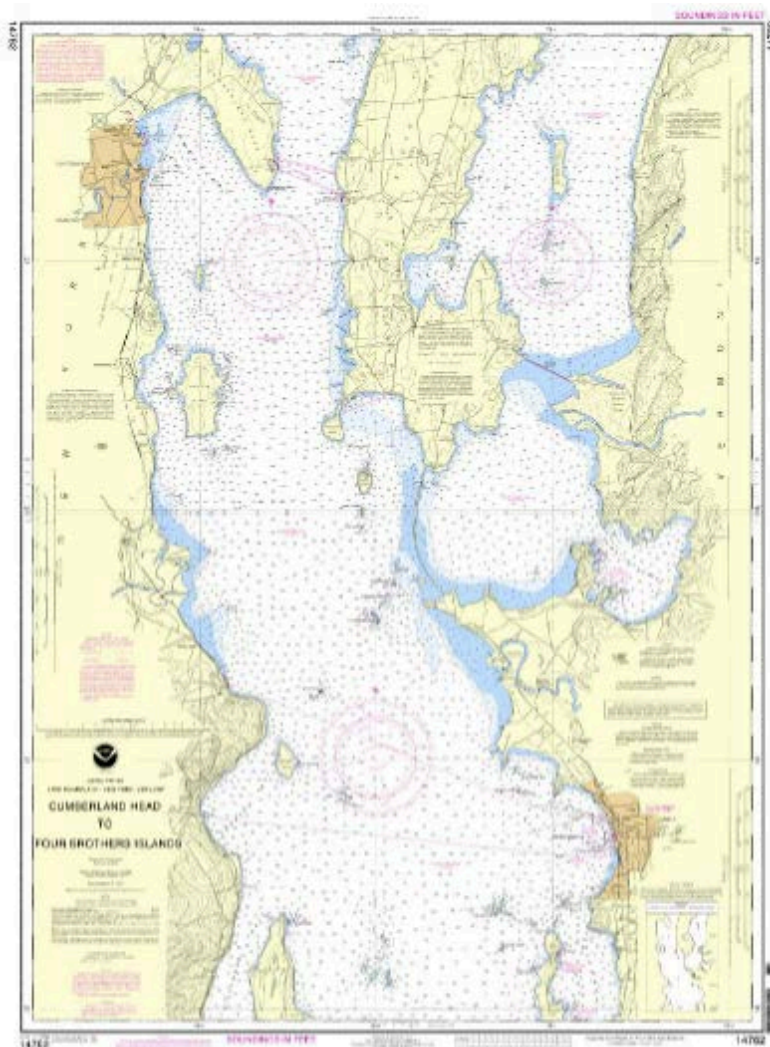


**Figure 2.5.** Chart 14782 (Cumberland Head to Four Brothers Islands).

Figure 2.5 shows NOAA Chart 14782, which covers the Cumberland Head to Four Brothers Islands area of Lake Champlain in New York and Vermont. Most nautical charts are at least a couple of feet in each direction, a good fit for a ship's plotting table but requiring folding on a small boat. Even with the very small size shown in the figure, one can see that there is a lot of information written on the chart that is often as important as the waterway data itself.

### 2.3.1. Chart Reference Data

The single best identifier of a chart is the chart number, clearly marked on the outer boundary in all four corners. Additional information, such as the date of publication, is generally shown in one place; the information in Figure 2.6 appears in the lower left corner of chart 14782. This

label indicates the 25th edition, published in January 2006, with corrections based upon Notices to Mariners through January 14, 2006 and Local Notices to Mariners through January 10, 2006. The chart note, in purple, confirms that this chart has been corrected from NMs and LNMs.



**Figure 2.6.** Chart number and date of publication (Chart 14782).

Charts also have a name that identifies the specific geographic area that they cover, as well as the publisher of the chart. The section of the chart in Figure 2.7 identifies this chart's geographic coverage as well as NOAA as the publisher. All current nautical charts in the U.S. come from NOAA and, in some cases, additional agencies (particularly true in waters that border other countries).
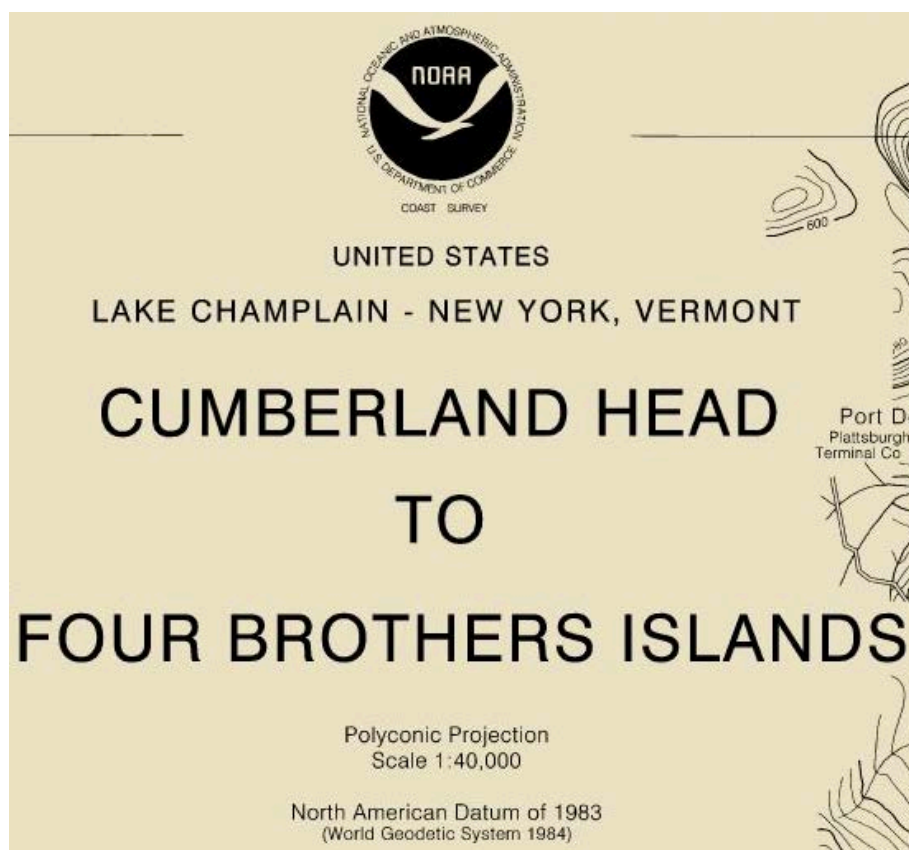


**Figure 2.7.** Chart title and other information (Chart 14782).

Chart 14782 has a scale of 1:40,000, putting it in the *harbor chart* class. The identification section also indicates that the chart uses a polyconic projection, as do most U.S. charts covering the Great Lakes and its connecting waterways. (Most nautical charts on the open seas employ a Mercator projection. Appendix B describes the difference between the two projections.)

Figure 2.8 presents a portion of Chart 14782 that shows the latitude and longitude axes. The vertical lines are the meridians, or lines of longitude, on which north-south position is measured. The vertical line on the right edge of the chart show the region between 44°25'N to 44°30'N latitude. There are ten black and white boxes between these two reference points, so each box represents half a minute, or 30".
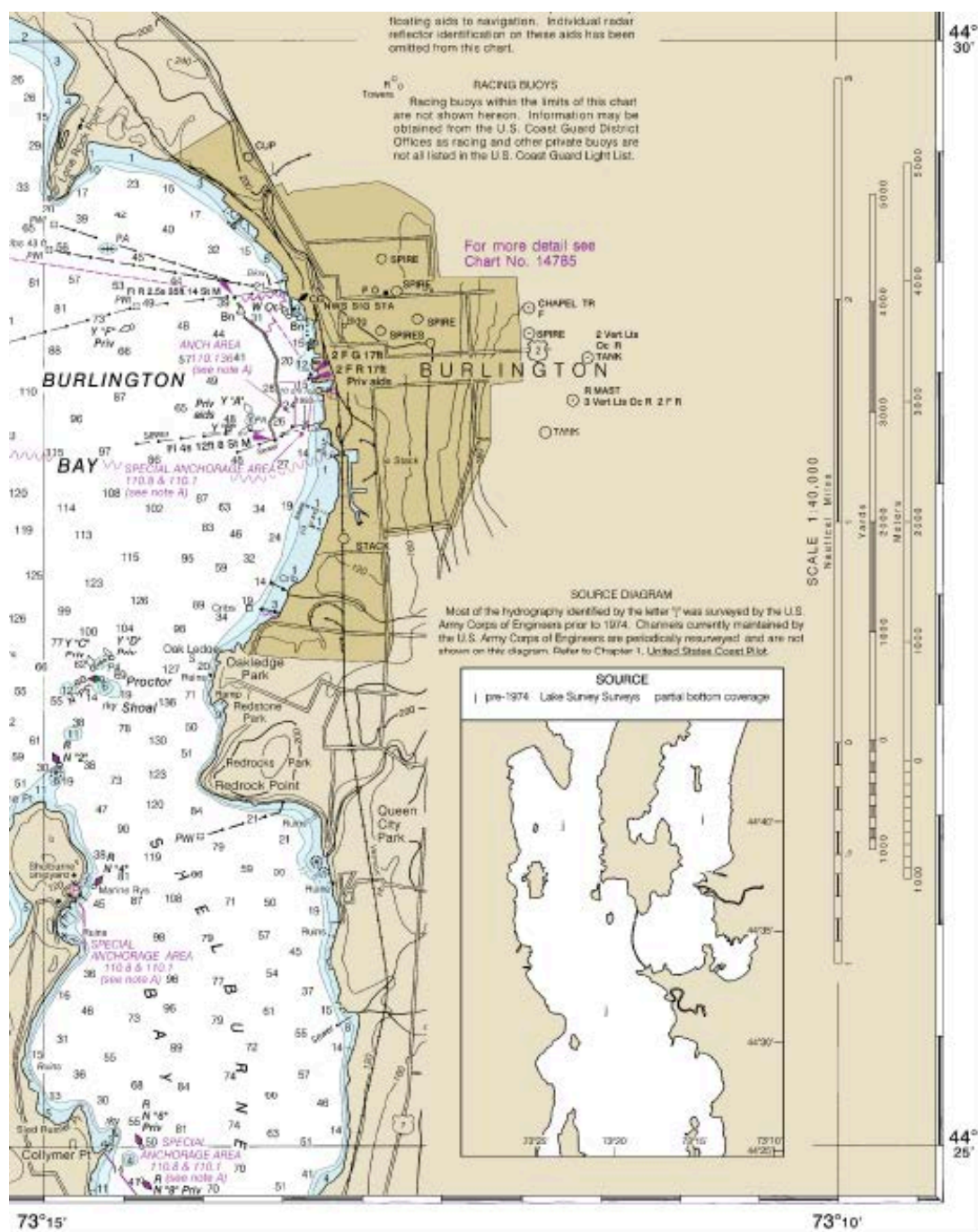


**Figure 2.8.** Latitude and longitude scales on Chart 14782.

The horizontal lines are the parallels, or lines of latitude, on which east-west position is measured. The horizontal line on the bottom edge of the chart shows the region between 073°10'W and 073°15'W longitude. Again, each alternating black and white box is 30".

Note that the longitude scale (horizontal) appears to be geographically shorter than the latitude scale (vertical). This is because one degree of latitude represents the same linear distance regardless of the position on the globe, whereas a degree of longitude gets linearly smaller as the lines approach the poles (where the lines come together).[18]  Only at the Equator is a degree of latitude and a degree of longitude equal to the approximately same linear distance. (Appendix C describes this issue in more detail.)

One *degree* of latitude (and one degree of longitude *at the Equator*) represents 60 nautical miles. Therefore, a *minute* represents one *nautical mile*, which equals 1.15 statute (land) miles or 6,076.12 feet (1,852 meters). A *second* is approximately 101.27 feet (30.9 meters).
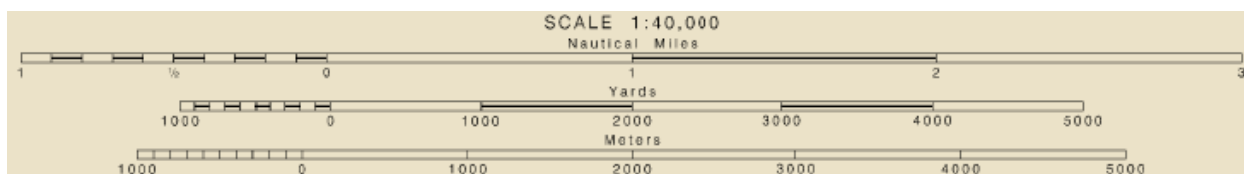

**Figure 2.9.** Legends for distance on Chart 14782.

Figure 2.9 shows the legend on Chart 14782 for the distance scales on the chart. Note that one nautical mile is the same length as one minute on the (vertical) latitude scale on the chart; one minute on the (horizontal) longitude scale is less than a nautical mile. A nautical mile can always be determined from the latitude axis of almost any nautical chart and can generally never be determined from the longitude axis. (This will come up again in the plotting exercises.)
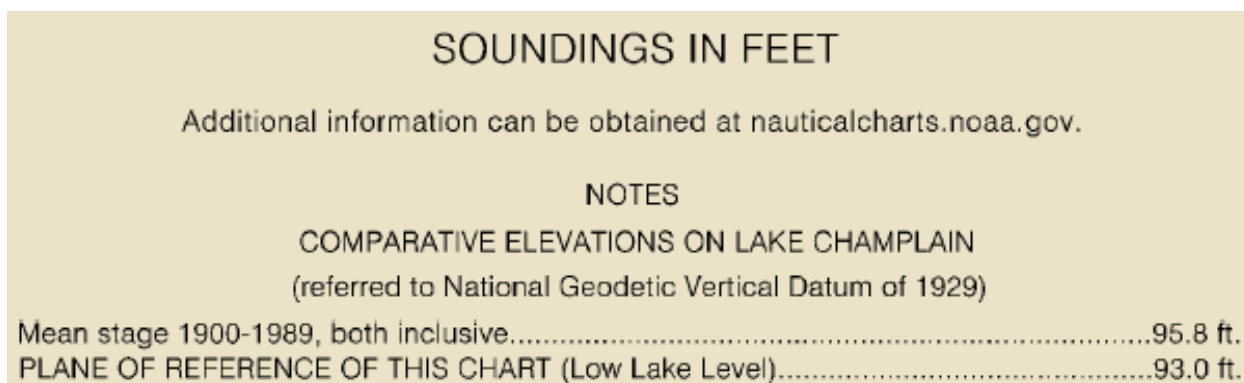

**Figure 2.10.** Sounding information for Chart 14782.

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[18] The fact that one degree of longitude represents a different linear distance depending on latitude was a significant problem for mariners prior to the development of accurate clocks in the 1700s. For an excellent description of the Longitude Act of 1714 and the development of precise nautical clocks, see *Longitude* (Sobel, 1995).

Numbers over water on the chart represent the depth of the water at various points. It is important to know in what units the depths are measured and the reference point for determining those depths. As Figure 2.10 shows, depth soundings on Chart 14782 are in feet; this statement is actually present on the chart in at least three places. The plane of reference is 93.0 feet, which is the low lake level. It makes sense to take soundings when the water is at its lowest because the soundings then represent the most conservative measurements of depth. The mariner is still responsible to know the actual lake level given local conditions in order to ensure that the soundings still paint an accurate picture at any given day and time.[19]

Many charts (including this one) provide a conversion table between feet, fathoms, and meters. A fathom is 6 feet.

### 2.3.2. The Compass Rose

One of the most prominent features on every nautical chart is the compass rose (Figure 2.11). The compass rose provides the reference for determining the direction of the vessel. North on the compass rose is at 0°, east is 90°, south is 180°, and west is 270°. The compass rose is generally depicted with two rings. The outer ring represents true, or geographic, north. The inner ring represents magnetic north, the heading that is generally shown on the compass of most recreational boats (since they are generally made of wood, fiberglass, or some other non-magnetic material).
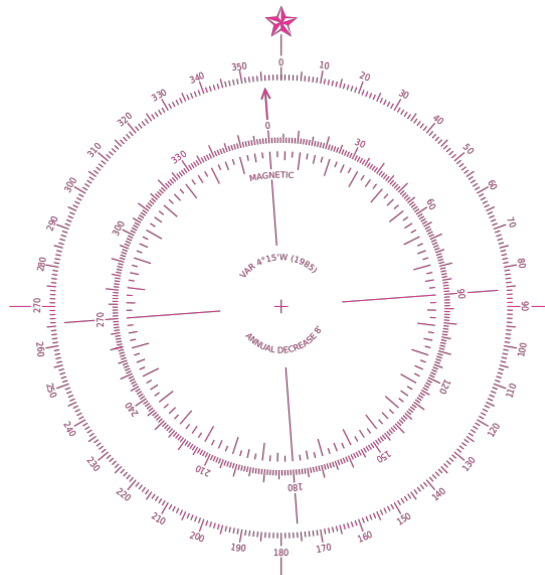


**Figure 2.11.** Compass rose.[20]

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[19] Tide tables, which are not discussed in this tutorial, assist the mariner in knowing how the water depth fluctuates on a daily basis, which can aid in planning. The NOAA Tides & Currents Web page can be found at *http://tidesandcurrents.noaa.gov/*.

[20] http://en.wikipedia.org/wiki/File:Modern_nautical_compass_rose.svg

Details about the magnetic compass and variation will be discussed in the sections on plotting and determining north on the chart and compass. Section B of *Chart No. 1* describes the compass rose to the level necessary for the recreational mariner.

*2.3.3. Landmarks*

Charts primarily illustrate features of waterways, but a description of major landmarks is provided to assist in navigation and determining one's location. Figure 2.12 shows the city of Burlington from Chart 14782. The detail here shows a few of the major roads and the location of a number of spires in downtown; note the presence of topographic lines of elevation representing the hill on which Burlington is built. The note (in purple) indicates that even more detail can be found using Chart 14785.
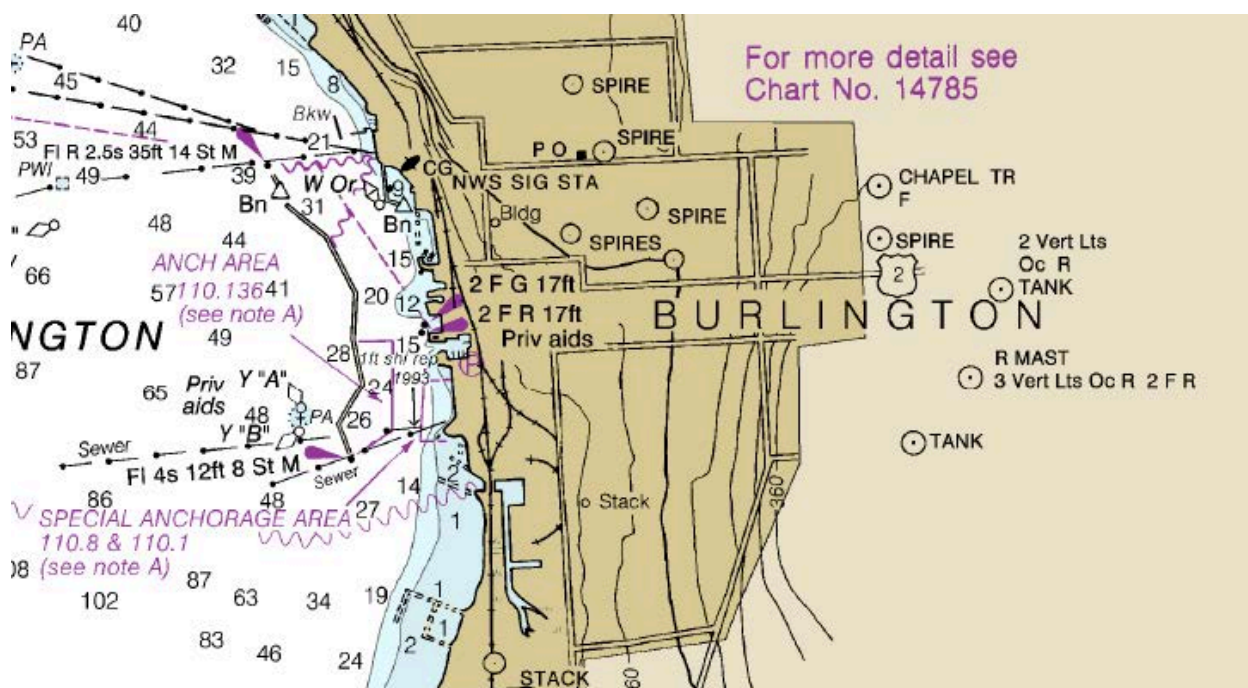


**Figure 2.12.** Landmarks in the city of Burlington (Chart 14782).

The chart also shows a tank and radio mast to the east of downtown (on the top of the hill). The tank has two vertical occulting[21] red lights on it, while the radio mast has an occulting red light and two fixed red lights in a vertical configuration.

The *Coast Pilot* (Volume 6) contains additional information about Burlington (referencing Charts 14782 and 14785):

> (75) Burlington, VT, just N of the entrance to Shelburne Bay, is the largest port on Lake Champlain. Several companies have dock facilities for receipt of petroleum products by barge. The Hilton Hotel, with a red lighted sign, is the most prominent object in the harbor approach.

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[21] An *occulting light* is one where the light is on for a noticeably longer time than it is off during the period of the light cycle.

(76) Burlington Breakwater North Light (44°28'50"N., 73°13'47"W.), 35 feet above the water, is shown from a white square lighthouse on the north end of the north breakwater.

### 2.3.4. Marginal Notes

Additional information on the charts appears in the form of marginal notes, which are printed in purple. The reference to Chart 14785 in Figure 2.12, for example, is such a note.
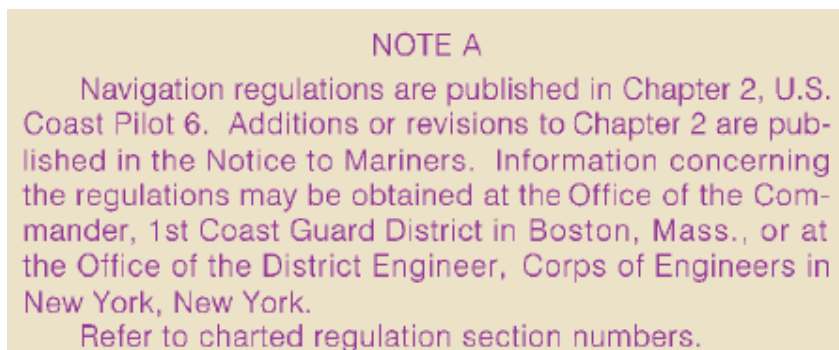


**Figure 2.13.** NOTE A from Chart 14782.

To the west of downtown Burlington is a special anchorage area with a statement to "(see note A)." Note A can be found looking elsewhere on the chart (Figure 2.13).

### 2.3.5. Symbols for Aids to Navigation

The primary purpose of nautical charts is to provide the characteristics of the water rather than the land. The primary reason that recreational boaters refer to charts is to learn about the navigable channels, which requires understanding of the ATON symbols.

Figure 2.14 is a summary of the different types of red and green channel markers, and the chart symbols that represent them. As shown:

- A green square represents a green beacon. The chart will also indicate the color (G) and the number on the dayboard ("7").
- A red triangle represents a red beacon. The chart will also indicate the color (R) and the number on the dayboard ("8").
- The "teardrop" symbol represents any light at a fixed position, such as red or green beacon with a light or a lighthouse. The notation with the symbol will indicate the color of the light and the flash rate, and might also include a beacon number, height of the light, and distance that the light can be seen. The light in the example on the left is a lit beacon number 5 that flashes (Fl) a green (G) light every six seconds (6s). The example on the right is for a lit beacon number 6 that flashes a red light every six seconds. Lit beacons and buoys will always blink the color of the ATON; i.e., red ATONs blink red and green ATONs blink green. Lighthouses blink white.

- The diamond symbol with a small circle at the bottom is a buoy. The example on the left shows a green (G) can (C) buoy marked with a number 3 ("3") while the example on the right is for red nun buoy number 4. Since the "can" and "nun" shapes are actually implied by the color, some charts do not include the C and N.
- The diamond symbol with a magenta circle at the bottom is a lit buoy. The example on the left shows a green (G) buoy marked with a number 1 ("1") that flashes a green light every four seconds. The example on the right is for red buoy number 2, flashing a red light every four seconds.
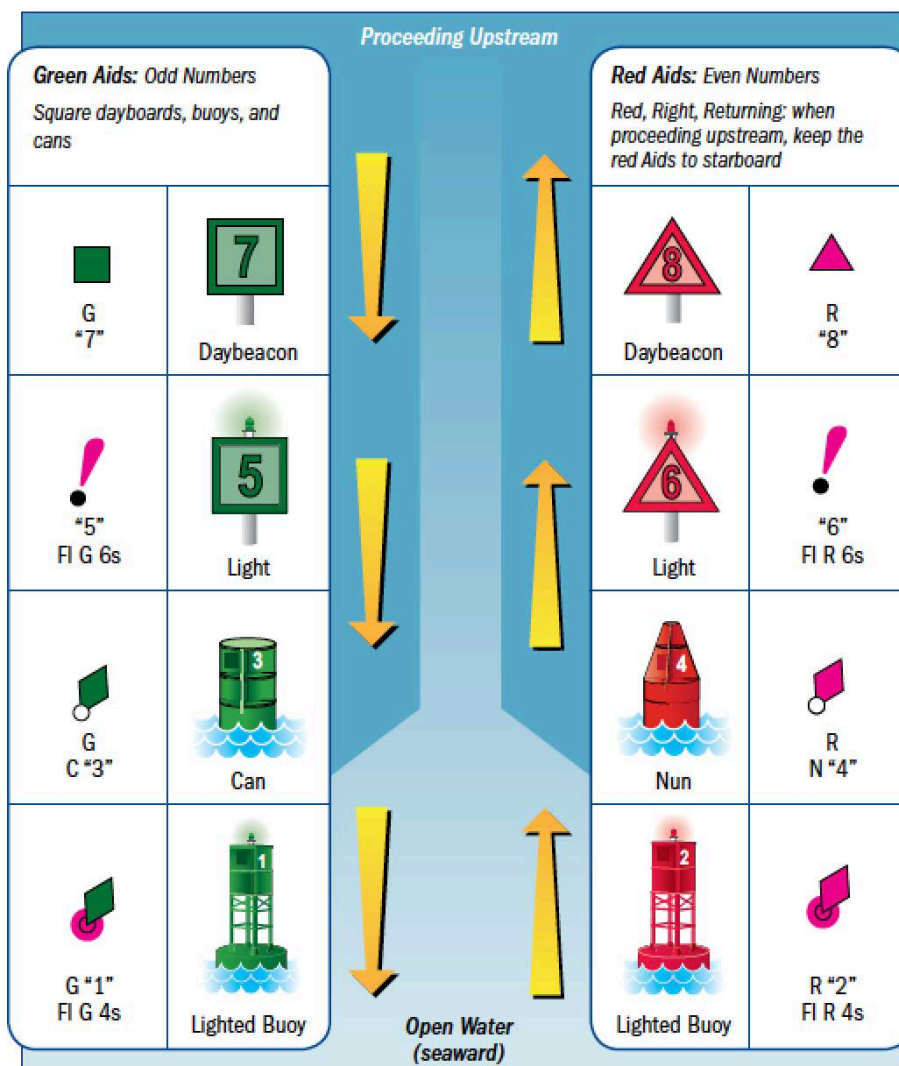


**Figure 2.14.** Channel markers and symbols.
(From *U.S. Aids to Navigation System*).

Although not discussed in detail here, the final red/green ATON is a *preferred channel* or *junction marker*. These beacons and buoys are used at a junction on the water to indicate the "best" channel. Junction markers are both red and green with one of those colors above the other. To stay on the preferred (or primary) channel, interpret the marker as if it were the top

color and keep the marker to the correct side of the boat for that color. Go on the secondary channel by interpreting the marker as if it were the lower color.

Preferred channel markers never have a number but sometimes have an alphabetic identifier. If lit, they blink the top color in a pattern of "two blinks, quiet, one blink" (2+1).
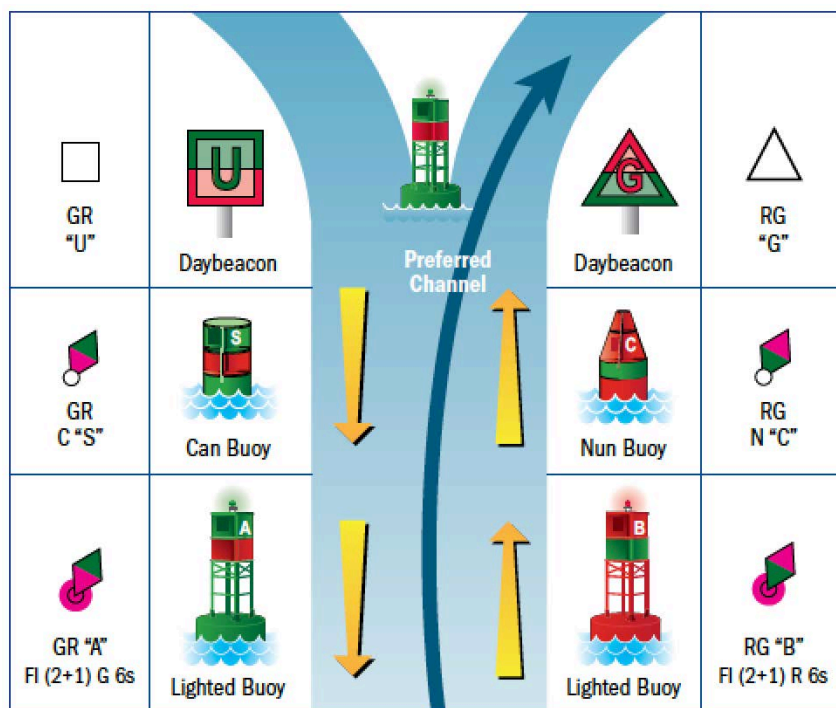


**Figure 2.15.** Preferred channel markers and symbols.
(From *U.S. Aids to Navigation System*).

The examples in Figure 2.15 include:

- A white square indicates a green-over-red (GR) beacon (the shape matches the upper color; green would be a square). The color scheme is reinforced by the letters, GR. In this example, the beacon is identified on the chart with the letter U ("U").
- A white triangle indicates a red-over-green (RG) beacon (again, the shape matches the upper color and red would be a triangle). In this example, the beacon is identified on the chart with the letter G ("G").
- A green and red diamond (buoy) symbol with green on top represents a green-over-red (GR) can (C) buoy, this one identified with the letter "S."
- A red and green diamond (buoy) symbol with red on top represents a red-over-green (RG) nun (N) buoy, this one identified by the letter "C."
- A green-red diamond with a magenta circle represented a green-over-red (GR) lit buoy. This one will flash a green light in a 2+1 pattern every six seconds and is identified by the letter "A."

- A red-green diamond with a magenta circle represented a red-over-green (RG) lit buoy. This one will flash a red light in a 2+1 pattern every six seconds and is identified by the letter "B."

### 2.3.6. Examples from the Charts

The examples in this section are meant to introduce some of the details and symbols on a chart that might ordinarily be overlooked by a recreational mariner; if you are not looking for a dive site, for example, you might not care much about the location of a wreck unless it is a hazard to navigation. While navigational markers are shown and described, this is not a tutorial about the IALA-B system. Bottom characteristics and other symbols are also shown; *Chart No. 1* and the Light Lists are essential supplementary resources.
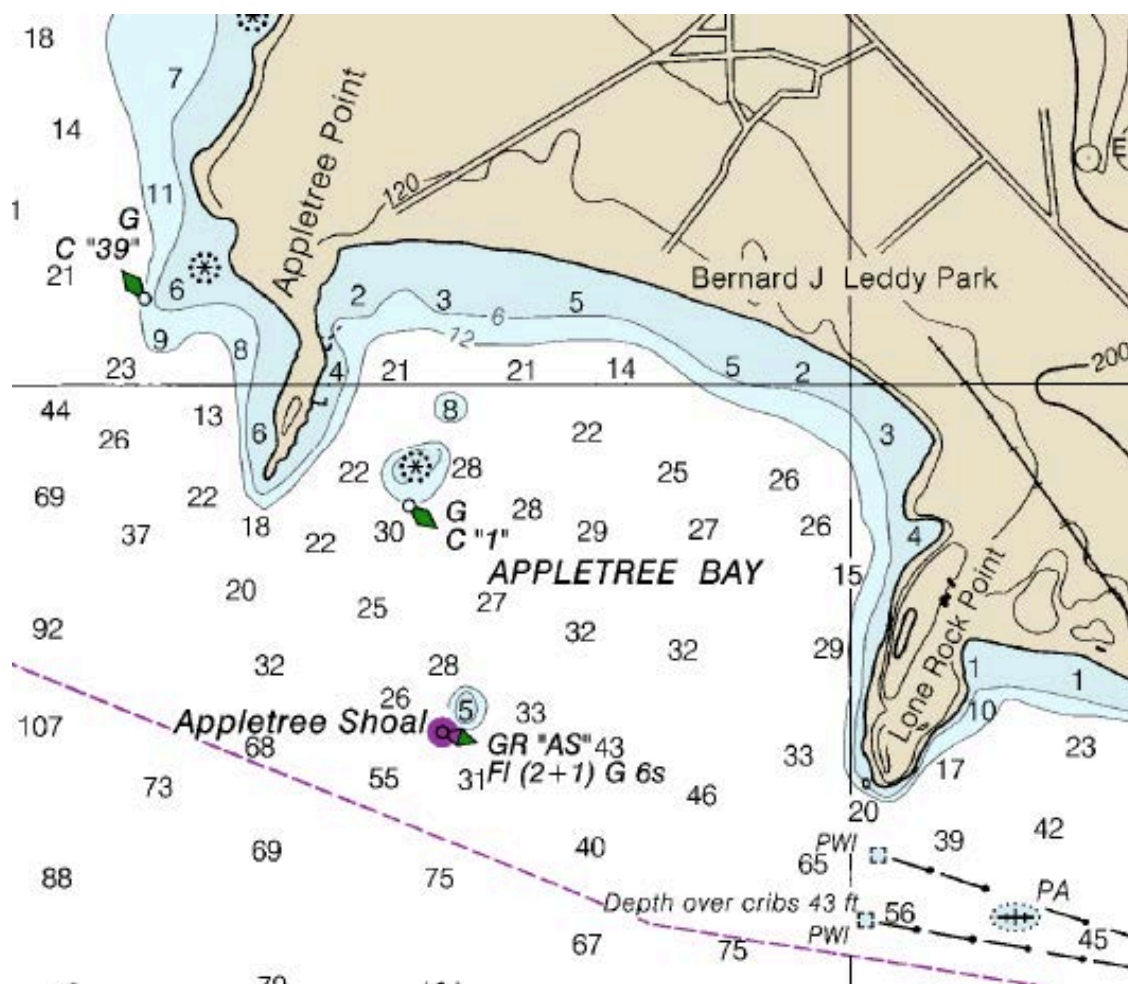


**Figure 2.16.** Appletree Bay, from Chart 14782.

The first chart snippet shows the Appletree Bay portion of Chart 14782 (Figure 2.16). All of the following information can be found on this chart:

- The numbers that have no other contextual meaning are depth soundings. The legend on this chart indicates that soundings are in feet. Note that the water with depths at 6 feet (1 fathom) or less are shaded in dark blue, depths between 7-12 feet (2 fathoms) are shaded in light blue, and white indicates "deep" water.
- Green can buoy number 39 can be found in the upper left of the chart area, to the west of Appletree Point. (A larger view of this body of water would show that this buoy is part of the markings on Lake Champlain; southbound traffic would keep this buoy to the left (port side) of the boat.
- Just to the east of Appletree Point – and just south of another shoal – is green can buoy number 1. This buoy is part of the path leading east into the city of Burlington. This buoy would be kept to the left of the boat.
- The third buoy just south of Appletree Shoal is a preferred channel marker with the letters "AS" on it. This is a lit buoy, flashing a green light in a 2+1 pattern every six seconds. While a vessel can safely pass to the left or right, the preferred channel would keep this buoy on the left of the boat.
- Two potable water intakes (PWI) can be seen south of Lone Rock Point. Both terminate in cribs that are in about 43 feet of water (per the wording on the chart). A pipeline (possibly disused) leads to each of the cribs.
- A wreck can be found to the east of the two cribs and between the two pipes. Because the position of the wreck is not known exactly, it is marked PA (position approximate).[22]
- The red dashed line represents the route of a scheduled ferry.[23]

All of the information found here can be interpreted using the information in *Chart No. 1*. For this chart fragment, the following sections of *Chart No. 1* are particularly helpful:

- Section B: Positions, Distances, Directions, Compass
- Section K: Rocks, Wrecks, Obstructions
- Section L: Offshore Installations
- Section P: Lights
- Section Q: Buoys, Beacons

Additional information about markers in Appletree Bay can also be found in the Light List for the region.[24] The entries for buoys "1" and "AS" are shown below, and include the latitude and longitude.[25] In addition, the entry for the "AS" buoy notes that it can be seen up to a nominal distance of three nautical miles and that it is a seasonal marker, replaced by a can from November 1 to May 1.

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[22] The wreck indicated is called the *Horse Ferry*, the only known wreck of a horse-powered vessel in North America.
[23] This ferry runs between Burlington and Port Kent, New York. Knowing the route of a scheduled ferry is important as it has right-of-way over most other boats in the area.
[24] Lake Champlain information is in *Volume I: Atlantic Coast (St. Croix River, Maine to Shrewsbury River, New Jersey)*.
[25] Note that latitude and longitude are expressed to the thousandth of a second, which is roughly 1.2 inches (3 cm).

**Appletree Bay**

| 39605 | Appletree Point Buoy 1<br>At southeast side of 8-foot<br>spot. | 44-29-47.174N<br>073-16-05.963W | | | Green can. | |
| 39610 | Appletree Shoal Lighted Buoy<br>AS | 44-29-23.175N<br>073-15-59.963W | Fl (2+1)G 6s | 3 | Green and red<br>bands. | Replaced by can from Nov 1 to<br>May 1. |
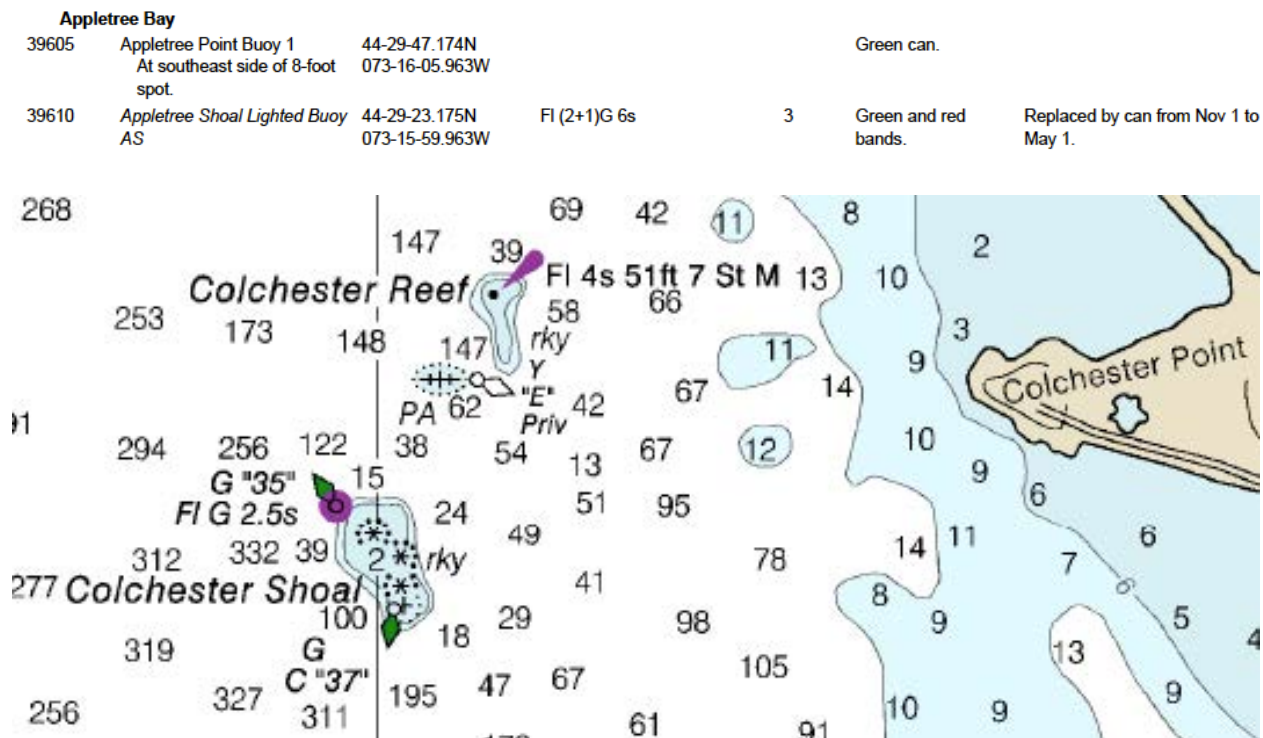


**Figure 2.17.** Colchester Reef and Colchester Shoal, from Chart 14782.

Figure 2.17 shows another example from Chart 14782 in order to display a few more chart symbols. The information that is recorded here includes:

- There is a white light at the north end of Colchester Reef (the absence of any other color code indicates that the light is white). The light flashes once every four seconds, stands 51 feet high, and has a nominal visibility of seven statute miles (*Fl 4s 51 ft 7 St M*).
- The seabed around Colchester Reef and Colchester Shoal is rocky ("rky").
- Just south of the reef (position approximate) is a wreck, marked by a yellow buoy, denoted "E."[26] This buoy is privately maintained (Priv).
- There is a green buoy at the north end of Colchester Shoal, with the number "35". This is a lighted buoy, with a green light that flashes every 2.5 seconds (*Fl G 2.5s*).
- There is a green can buoy marked with the number "37" at the south end of the shoal.

The Light List provides information about these four markers, as shown below. As before, the entries show the latitude and longitude; since the wreck is denoted with a *PA* and the two buoys are not fixed, the most reliable position of the four is the light on the reef. The Colchester Reef Light entry states explicitly that it is a white light and stands 51 feet high; the nominal visibility in the light list is given in nautical miles rather than statute miles, which is why that entry shows a six whereas the chart shows a seven. The entries for the buoys on Colchester Shoal indicate that they are only seasonally maintained. Finally, the Light List shows that buoy "E" is a yellow spherical marker maintained by the Lake Champlain Underwater Preserve.

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[26] This wreck is called the *Phoenix*.

| | | | | | | |
|---|---|---|---|---|---|---|
| 39540 | COLCHESTER REEF LIGHT | 44-33-18.400N 073-19-44.300W | Fl W 4s | 51 | 6 | NG on post on granite caisson. | |
| 39565 | *Colchester Shoal Lighted Buoy 35* At northwest point of shoal. | 44-32-58.070N 073-20-05.572W | Fl G 2.5s | | 3 | Green. | Maintained from May 1 to Nov. 1. |
| 39570 | Colchester Shoal Buoy 37 At southeast end of shoal. | 44-32-47.920N 073-19-57.713W | | | | Green can. | Maintained from May 1 to Nov. 1. |

**Lake Champlain Underwater Preserve**
*Aids maintained from June 1 to Nov. 1.  Aids mark historic shipwreck diving sights.*

| | | | | | |
|---|---|---|---|---|---|
| 39655 | - Buoy E | 44-33-01.000N 073-19-48.000W | | Yellow sphere. | Private aid. |

Figure 2.18 shows a portion of Chart 14785 (Burlington Harbor), also seen in Figure 2.12. The information shown here includes:

- The light just to the north of the breakwater – naturally called the North Breakwater Light – flashes red every 2.5 seconds; standing at 35 feet, the nominal visibility of the light is 14 statute miles (*Fl R 2.5s 35 ft 14 St M*).
- Just south of the light, at the opening in the breakwater, is a white beacon (*W Bn*).
- A pipe (black dashed line) extends past the north end of the breakwater, running roughly east-west. There is also a submarine cable (red squiggly line) in that area, leading to the light.
- The route of the ferry (red dashed line) is just to the north of the light.
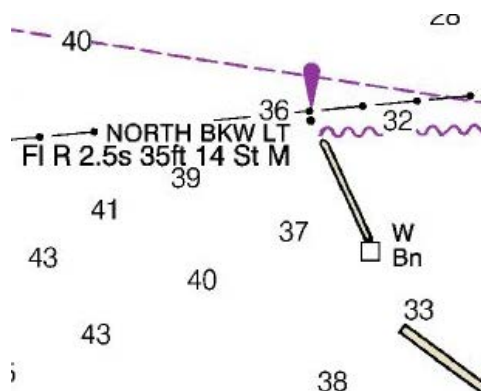


**Figure 2.18.** Burlington harbor breakwater, from Chart 14785 (Burlington Harbor).

The next example shows the Deer Island and President Roads portion of Massachusetts Bay from Chart 13267 (Figure 2.19). The first item of particular interest is the light to the south of Deer Island. The codes under the "DEER ISLAND" label on the chart mean:

- This is an alternating white/red light with a 10s rotation period. The light stands 53 feet high and can be seen from a nominal distance of 11 (nautical) miles.
- The light has a horn.

- There is a fixed red light at a height of 15 feet that can be seen from a distance of 6 (nautical) miles.
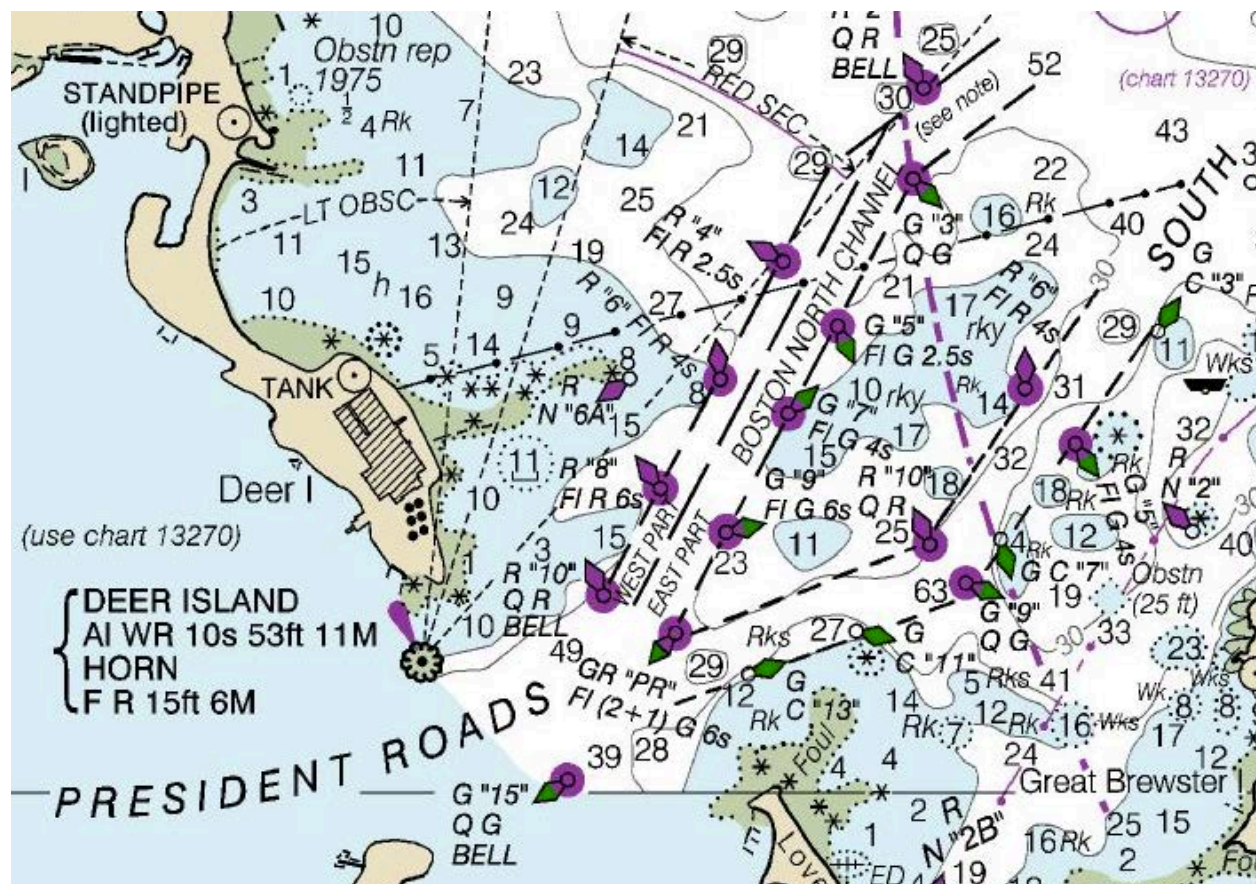


**Figure 2.19.** Deer Island and President Roads section of Chart 13267 (Massachusetts Bay).

The label "LT OBSC" can be seen north of the tank that is north of the light. This refers to a region where the view of the light is obstructed. In addition, the label "RED SEC" appears roughly northeast of the light, referring to the sector where a vessel at sea can see the red light.

The chart provides a lot of information, but this is an example where the Light List provides so much more. The Volume I *Light List* has this entry for Deer Island:

| 10795 | **Deer Island Light**<br>On south end of spit. | 42-20-23.461N<br>070-57-16.225W | Al WR 10s | 53 | 11<br><br>R 11 | Red cylindrical<br>tower; black<br>cylindrical pier.<br>53 | Obscured from 112° to 186°.Red<br>danger sector from 198° to 222°.<br>HORN: 1 blast ev 10s (1s bl). |
| 10797 | DEER ISLAND DANGER<br>LIGHT<br>On south end of spit. | 42-20-23.400N<br>070-57-16.000W | F R | 15 | 6<br><br>R 10 | | Red from 198° to 222°. |

The Light List provides the exact location of both the primary light and the red danger light, and indicates that the horn sounds a one-second blast every 10 seconds. The entry also indicates that the light is obscured in the range of 112° to 186°; these bearings are true compass

headings *from the perspective of the vessel*. In addition, the red danger light can be seen from a vessel at sea from the true headings between 198° to 222°.

The other features of interest on the chart are the shipping channels leading out of President Roads (the outbound channel begins at the highest numbered buoys). Remember that in the lateral navigation system used in the U.S., red buoys are kept to the port side (left) of the vessel when going out to sea and the green buoys kept to the starboard (right) side.

The channel starts between the Deer Island light and the green buoy ("15") to the southeast of the Deer Island light. This buoy has a bell and has a quickly flashing green light (*Q G*).

Continuing northeast towards the channel is a lighted preferred channel marker, denoted "PR." Since the top band is green, this buoy indicates that vessels should generally proceed toward the Boston North Channel (i.e., keeping this buoy to the vessel's starboard side). This buoy flashes a green 2+1 pattern every six seconds.

The north (left, as you go out to sea) side of the Boston North Channel is marked by five red buoys with the following characteristics:

- "10" – A lighted buoy with a bell and a quick flashing red light.
- "8" – A lighted buoy with a red light that flashes every six seconds.
- "6" – A lighted buoy with a bell and with a red light that flashes every four seconds.
- "4" – A lighted buoy with a red light that flashes every 2.5 seconds.
- "2" – A lighted buoy with a bell and a quick flashing red light.

The south ("right") side of the Boston North Channel is marked by four green buoys with the following characteristics:

- "9" – A lighted buoy with a green light that flashes every six seconds.
- "7" – A lighted buoy with a green light that flashes every four seconds.
- "5" – A lighted buoy with a green light that flashes every 2.5 seconds.
- "3" – A lighted buoy with a quick flashing green light.

A vessel might choose to take the south channel. The north ("left") side of the south channel is marked with two red buoys:

- "10" – A lighted buoy with a quick flashing red light.
- "6" – A lighted buoy with a red light that flashes every four seconds.

The south ("right") side of the south channel is marked with six green buoys:

- "13" – A can buoy.
- "11" – A can buoy.

- "9" – A lighted buoy with a quick flashing green light.
- "7" – A can buoy.
- "5" – A lighted buoy with a green light that flashes every four seconds.
- "3" – A can buoy.

The examples here show that there are many subtleties and nuances related to properly interpreting the aids to navigation and mariners are well advised to study the charts in their boating area and, where possible, learn the local waters from local boaters. Some examples of the mixed rules in understanding the buoys where the ICW meets other bodies of water can be found in these last examples.
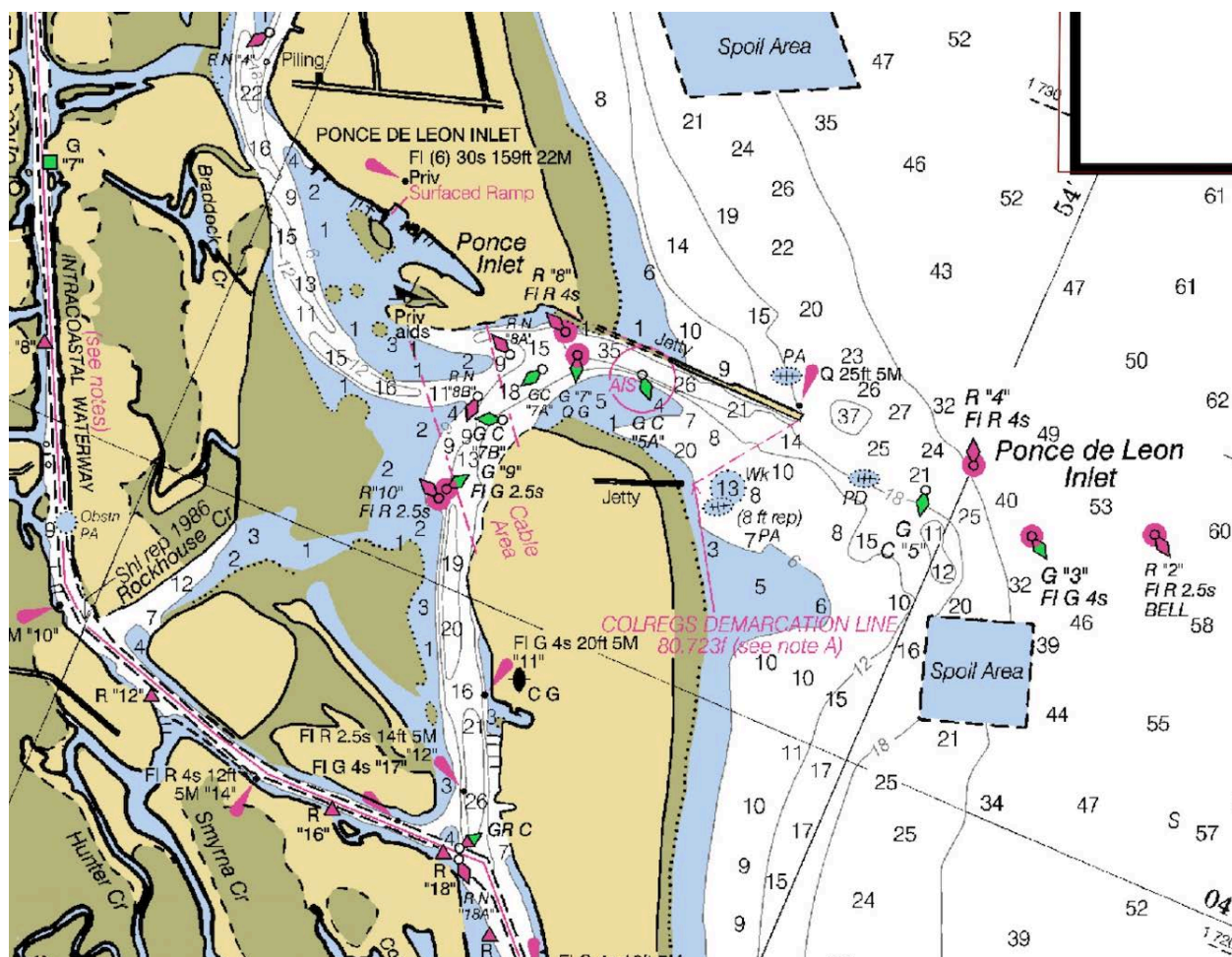


**Figure 2.20.** Area around Ponce de Leon Inlet from Chart 11485
(Intracoastal Waterway Tolomato River to Palm Shores).

Figure 2.20 is a portion of Chart 11485 (Intracoastal Waterway Tolomato River to Palm Shores), showing Ponce de Leon Inlet, south of Daytona Beach, Florida. The most prominent feature here is the privately-maintained lighthouse, which flashes a white light six times every 30 seconds. Standing at 159 feet, this is the tallest lighthouse in Florida. The light can be seen at a distance of 22 nautical miles.

The entrance to the channel starts between red buoy #2 (with a bell and red light that flashes every 2.5 seconds) and green lighted buoy #3, shown at the lower right. The entry continues westerly between red buoy #4 and green buoy #5. With the jetty on the right, the safe passage is between buoys #7 and #8, and then turns south between buoys #7A and #8A, and onward past buoy #9.

Note from this chart snippet that the marked channel continues south. If a boater continues in that direction, they will meet the ICW. If their intention is to go north to Daytona Beach, they can turn north onto the ICW on the Ponce de Leon Cut (which is on the very western edge of the figure.)

Local boaters often save time by making a right turn to the north in the area of red buoy #8A. Because of rapid shoaling in this area, the USCG has not marked this as a navigable channel and, therefore, there is a distance of approximately one mile with no channel markers.
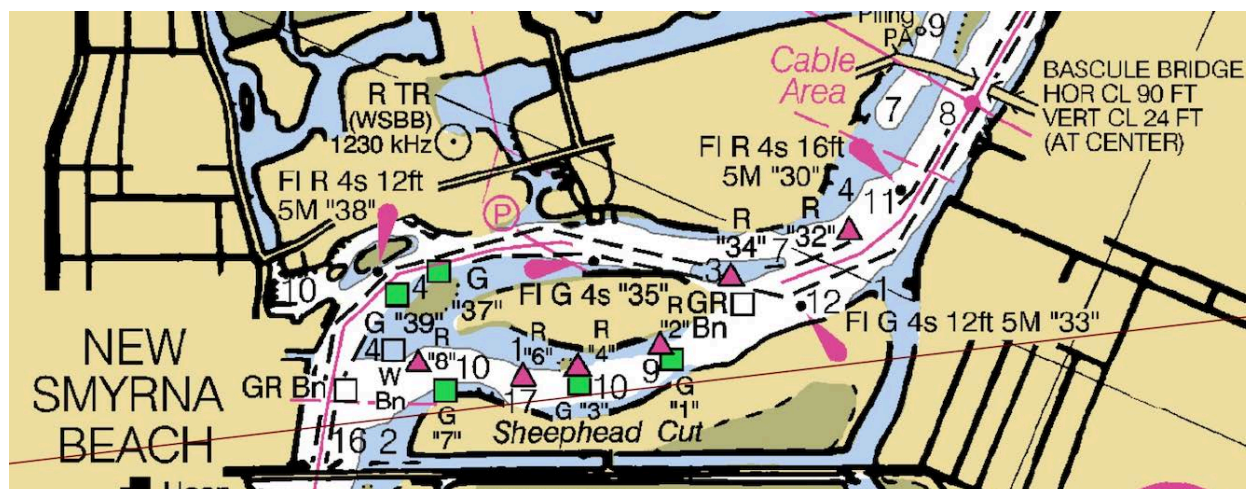


**Figure 2.21.** Area around Chicken Island in New Smyrna Beach from Chart 11485.

As a boater proceeds south of Ponce Inlet on the ICW, they follow the Indian River and get to a couple of bridges and a bifurcation in the waterway in New Smyrna Beach (Figure 2.21). There are a lot of markers in this section of the river! The first landmark of note is the George E. Musson Bridge, known locally as the North Causeway or Coronado Beach Bridge. The bridge is listed as a *bascule bridge*, which is a draw bridge. The horizontal clearance (i.e., width of the opening on the water) is 90 feet and the vertical clearance (i.e., height) of the bridge is 24 feet at the center (at mean high tide). A large power or sailing vessel needs to know this information because if they are too large, they will need an opening – and will need to know how to identify the bridge.

Proceeding south on the ICW, a boater will come to a red light (#30), a red beacon (#32), and a green light (#33). At this point, the waterway divides, going around Chicken Island (not named on the chart). The junction is noted by "GR Bn," denoting a beacon (i.e., a dayboard) that is

green-over-red. By keeping the green mark on the port side, the primary channel is the ICW and proceeds north of the island. At this point, the boater encounters a red beacon (#34), green light (#35), green beacons (#37 and #39), and a red light (#38).

By keeping the red mark of the junction beacon on the starboard side of the boat, the secondary channel proceeds on the southside of Chicken Island, known as Sheephead Cut. At this point, the channel is marked by beacons starting at red #2 and green #1. The Cut ends at red #7 and green #8.

At this point, Sheephead Cut joins the ICW at the more southern and western junction marker, also denoted "GR Bn." The ICW continues south under a fixed bridge, known as the South Causeway Bridge.
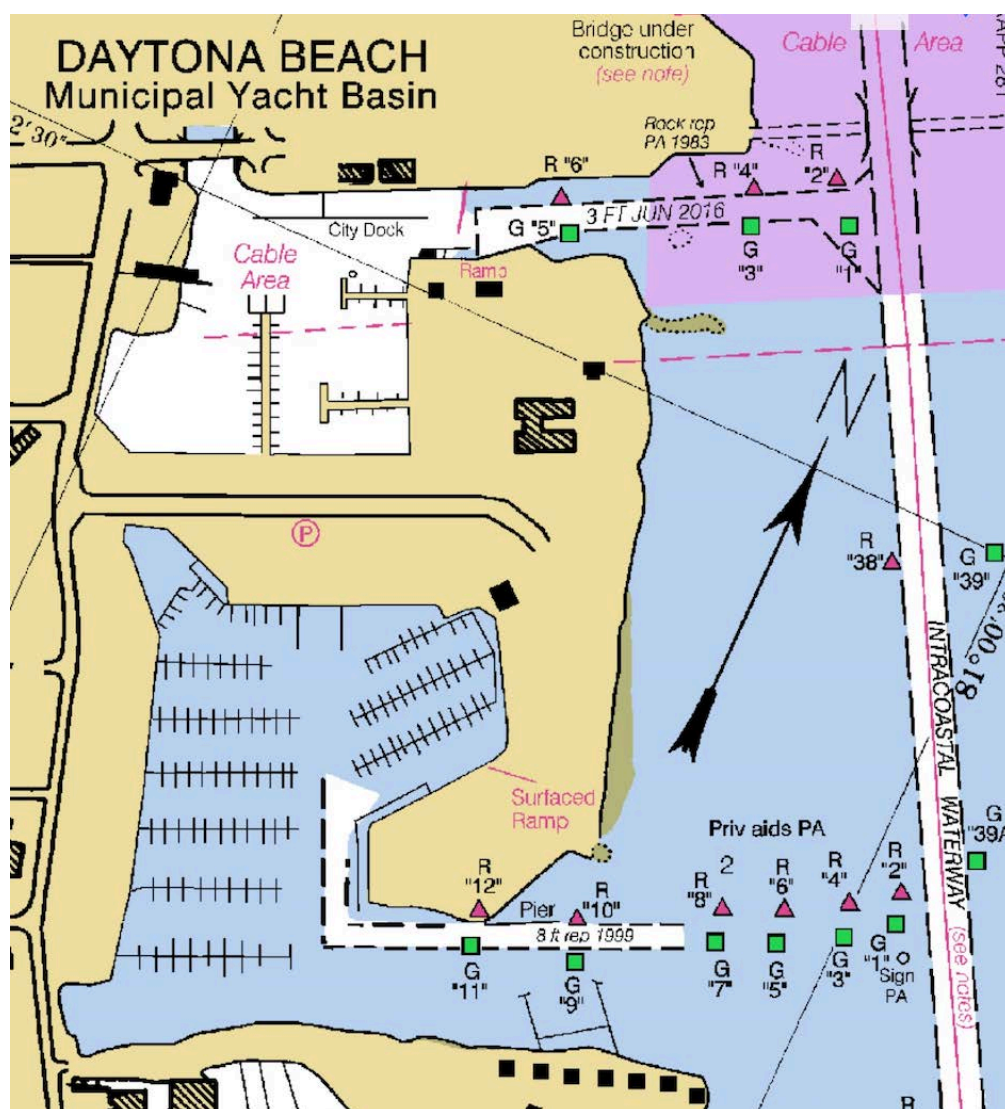


**Figure 2.22.** Daytona Beach Municipal Yacht Basin inset from Chart 11485.

Finally, consider the chart snippet showing the Daytona Beach Municipal Yacht Basin (Figure 2.22). The ICW channel is found with green beacon #39A to the right, then between red beacon #38 and green beacon #39. Just south of the "Bridge under construction" is the entry channel to the city dock.[27] Note here that green beacon #1 is to the left and red beacon #2 is to the right (consistent with the red-right-returning rule when moving from a larger body of water to a small one). The safe channel here continues between beacons #3 and #4, ending at beacons #5 and #6.

This section glosses over the details of the channel marker system and does not begin to describe other marker buoy types. The discussion is meant only to give a glimpse to the information on a chart and the functionality of the markers, and clearly shows why additional educational is essential for properly interpreting the aids to navigation and safely navigating the waters.
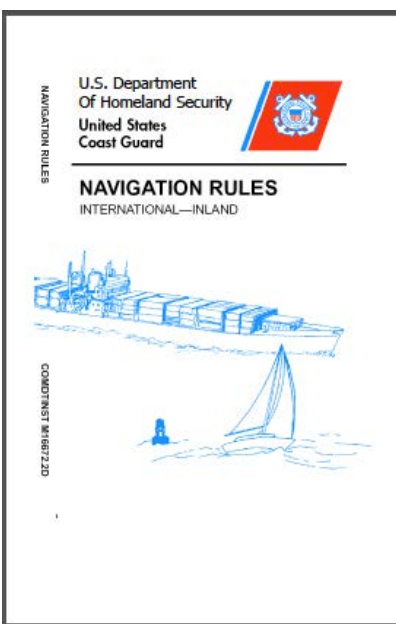


**Figure 2.23.** *Navigation Rules and Regulations Handbook* (USCG, 2014).

But even understanding the aids to navigation is not sufficient; boaters need to understand the rules of the road, including safe passing maneuvers, how to handle crossing situations, which vessels have priority over other vessels, lighting and sound requirements, and much more. The mariner's rules of the road are contained in a document called the *Navigation Rules and Regulations Handbook*[28] (Figure 2.23). Known as the collision regulations (or *colregs*), this document describes the protocol for vessels in inland and international waters. All mariners should be familiar with the basics of the colregs.

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[27] This chart shows a bridge under construction. The former Veterans Memorial Bridge was a bascule bridge, demolished during the summer of 2016, and still shows on some charts. A new, fixed bridge opened in August 2020. Be sure to always use the most up-to-date information!

[28] http://www.navcen.uscg.gov/pdf/navRules/Handbook/CG_NAV_RULES_20140910.pdf

## 2.4. Summary

There are many reasons that the recreational mariner should have a thorough understanding of nautical charts. The primary reason, obviously, is safety. The charts provide necessary information that can help you avoid hazards, particularly when going into unfamiliar waters. But knowledge of charts can also add an element of enjoyment by having a greater understanding of familiar, and even unfamiliar, waters.

This section provides a very basic, rudimentary overview of issues related to obtaining and reading charts as well as accessing supplementary resources with which to better understand them. The focus here has been on paper charts.

Indeed, an increasing number of recreational boaters employ marine GPS units. There are many issues related to keeping the GPS unit up-to-date as well as managing the differences between the electronic and paper charts. Readers are urged to continue reading other resources, such as *How to Read a Nautical Chart* (Calder, 2012), to obtain more detailed information.

# Part 3: Plotting

This section presents basic information about the tools used for charting and some of the basic arithmetic needed in order to solve simple navigation problem. The section will also review the relationship between geographic north, magnetic north, and the compass on your vessel. Several simple navigation and charting problems will also be introduced with methods in which to solve them.

## 3.1. Which Way is North?

Nautical charts are always oriented so that true (geographic) north is towards the top of the chart and vertical lines run true north-south. Compasses, however, point towards magnetic north – and the difference between true and magnetic north is different at different parts of the globe. Issues with the compass are exacerbated by the effect of nearby metal on the compass.

This section will describe the relationship between the different perspectives of *north* and how they relate to each other. Understanding these relationships is essential to being able to solve navigational problems and then actually turning the solutions into actionable plans for your vessel.

### 3.1.1. The Compass Rose, Revisited

Figure 3.1 shows the compass rose, a common presence on every nautical chart. As described in Part 1 of this manual, the compass rose has two concentric rings, where the outer ring represents headings relative to true north and the inner ring represents headings relative to magnetic north. On the outer ring, 000° points to true, or geographic, north and always points towards the top of the chart. On this ring, 090° is true east, 180° is true south, and 270° is true west.

It has long been known to geologists and geographers that the magnetic north pole is *not* in the same place as the geographic north pole. The difference between true and magnetic north – called the *variation* – will depend upon where you are located on the globe.

The problem is exacerbated by the fact that the magnetic north pole is actually constantly moving, a phenomenon is known as the *wandering magnetic pole*.[29] Thus, the variation between magnetic and true north at any given spot is changing every year.

The center of the compass rose in the figure indicates that when this rose was drawn (1985), the variation between true and magnetic north was 4°15'W. Look closely to see that, indeed, magnetic north (i.e., 0° on the inner ring) corresponds to approximately 356° on the outer ring.

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[29] See NOAA (n.d., 2019) for more information about the wandering magnetic north pole. Historically, the shift has been approximately 10 miles (16 km) per year; current models show a change of 34 miles (55 km) per year.

The label in the center of the compass rose says that the variation deceases annually by 8' (i.e., 8'E). This is important information because the compass rose on most charts that recreational boaters use might be five, ten, or more years in age. In 1985, when this particular compass rose was drawn, magnetic north was 4°15'W of true north. By 2019, 34 years had elapsed meaning that the variation had moved 4°32' to the east; therefore, magnetic north was now 0°17'E of true north.
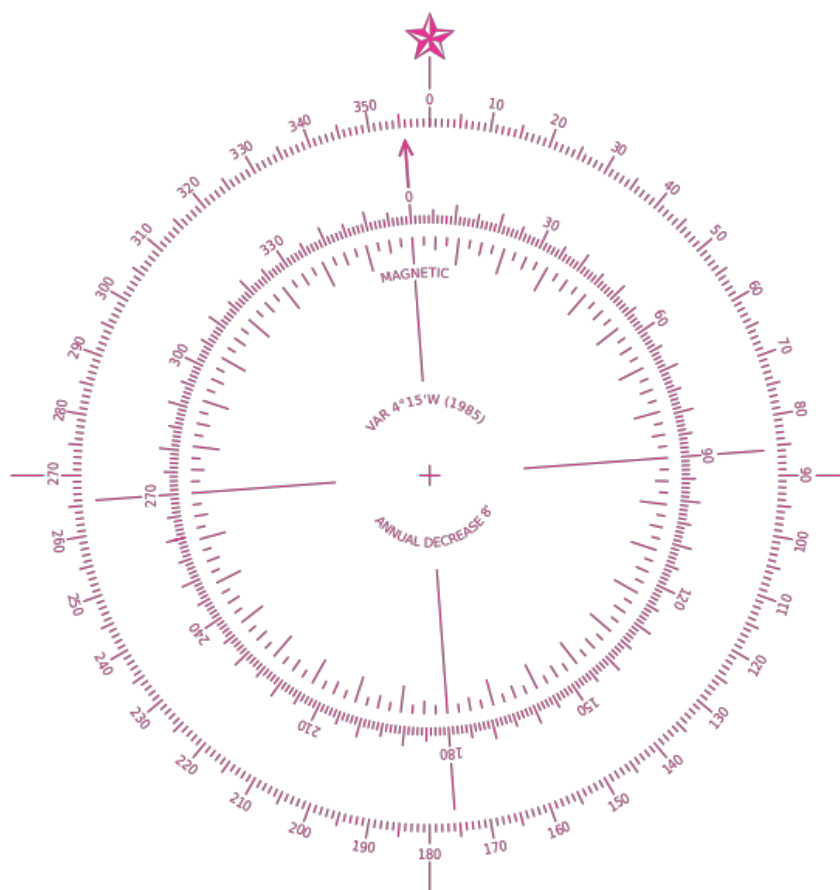


**Figure 3.1.** Compass rose.[30]

### 3.1.2. Deviation

The compass rose indicates how the compass pointing to magnetic north relates to true, geographic north. Metal near a compass, however, affects the compass reading. Most recreational boaters have vessels that are made of wood, fiberglass, and/or other non-magnetic materials, thus the construction of the vessel has minimal effect on the compass. Ships that are made of metal, however, may have a significant additional impact on the compass reading. This additional affect is called the *deviation*.

---

[30] http://en.wikipedia.org/wiki/File:Modern_nautical_compass_rose.svg

The deviation has a constant effect on the ship's compass (i.e., it doesn't change based upon location on the globe) and can be measured. The deviation will generally be of a different magnitude in different headings, so the measurements will be stated on a deviation table that is near the ship's compass. An example deviation table is shown below:

| Heading | Deviation | Heading | Deviation | Heading | Deviation |
|---------|-----------|---------|-----------|---------|-----------|
| 0° | 1°E | 120° | 1°E | 240° | 2.5°W |
| 30° | 1.5°E | 150° | 0° | 270° | 2°W |
| 60° | 2°E | 180° | 1°W | 300° | 0° |
| 90° | 3°E | 210° | 2°W | 330° | 0.5°E |

In practice, deviation applies only to a ship's compass. No additional correction is applied to a handheld compass because it is impractical, if not impossible, to measure its deviation. For a handheld compass, a deviation of 0° is used.

*3.1.3. Putting it all Together*

When a course is laid out, the heading is determined from the chart relative to true north. Accounting for variation and deviation is necessary to determine the proper heading on the ship's compass, which is referred to as the *course per steering compass*.

Simply stated, the course per steering compass is the sum of the true heading, variation, and deviation. Variation or deviation values that are to the west are added, while values to the east are subtracted. So, for example, if the true heading is 032°, the variation 3.5°W, and the deviation 1.5°E, then:

Course Per Steering Compass = 32 + 3.5 - 1.5 = 034°

There are a number of common acronyms that are used to teach this relationship. The most family-friendly acronym appears to be:

| | |
|---|---|
| Tele | TRUE |
| Vision | Variation |
| Makes | MAGNETIC |
| Dull | Deviation |
| Children | COURSE |
| | |
| add Wonder | add West (subtract east) |

Applying the example from above, then, yields:

| Tele | TRUE | 32° |
|------|------|-----|
| Vision | Variation | +3.5°W |
| Makes | MAGNETIC | 35.5° |
| Dull | Deviation | -1.5°E |
| Children | COURSE | 34° |

Moving (downward) from true to compass course heading – i.e., having determined the heading from the chart and converting to a heading to use on the ship's compass – is called *uncorrecting the compass*. Converting (upward) from a steering compass heading to a true heading is called *correcting the compass*. There are several Web sites that explain this in much more detail and give sample problems.[31]

## 3.2. Instruments for Plotting

An increasing number of mariners today rely on automated tools such as GPS for navigation and getting from one point to another. Indeed, a good marine GPS will not only replicate a chart's details, but can aid in determining course, distance, elapsed time, and position.

Nevertheless, a user of any form of technology should know something about what's happening "under the hood." In that spirit, this section introduces some of the hand tools used to manually perform routine navigational tasks using a nautical chart.

### 3.2.1. Parallel Rule and Roller Plotter

One of the tools most commonly associated with navigation is the *parallel ruler* (Figure 3.2).[32] A parallel ruler is primarily used to determine the heading on the compass rose from a line of direction from a chart (or vice versa). The "arms" connecting the upper and lower part of the ruler allow it to be moved across the chart without changing its orientation; this is called "walking" the ruler.



**Figure 3.2.** Parallel ruler.

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[31] One such site is *http://captnmike.com/2011/11/13/tvmdc-%E2%80%93-practice-%E2%80%93-correcting-and-un-correcting-the-compass/*.

[32] Instruments shown here are from Weems & Plath. Pictures are for example purposes only and should not be interpreted as a recommendation or product endorsement.

Use of a parallel ruler can be mastered with a little bit of practice. There are a number of tutorials on the Internet that might interest the reader including "How to Use Parallel Rulers" (*http://www.boatsafe.com/navigation/rules1.htm*) and "How to Use a Parallel Ruler and Compass Rose to Determine Direction" (*http://www.youtube.com/watch?v=xKSBYfscA80*).

The parallel ruler can also be used as a straight edge when connecting two points on a chart. Some parallel rulers (such as the one in the figure) have additional protractor markings around the edges allowing the course heading to be determined by moving the rule to any line of median (longitude) on the chart rather than only the compass rose.



**Figure 3.3.** Parallel, or roll, plotter.

A *parallel, or roll, plotter* (Figure 3.3) is an alternative to a parallel ruler. A parallel plotter has a roller that allows the device to be moved across a chart without changing its orientation. Most roll plotters have protractor markings, allowing the heading to be determined without having to move to a compass rose. The plotter can also be used as a regular straight edge.



**Figure 3.4.** Protractor triangle.

Another common tool is the *protractor triangle* (Figure 3.4). In addition to providing a straight edge, it can also help find the heading when used in conjunction with a parallel ruler or roll plotter.

*3.2.2. Dividers and Compass*

The second tool most commonly associated with plotting and navigation is a pair of *dividers* (Figure 3.5). Dividers are used to mark the distance between two points on the chart or to mark points on the chart at which to place a ruler, parallel ruler, or roll plotter.



**Figure 3.5.** Dividers.

Note that the dividers have two points at the end. Replacing one point with a pencil or lead marker turns this into a *compass*. Although not discussed further here, a compass can be used in charting to mark a circle (e.g., a swing circle when determining the area for an anchorage) or an arc (e.g., when estimating possible positions).

## 3.3. Arithmetic for Plotting

There are a number of basic arithmetic skills that are essential to being able to solve simple charting problems. This section will briefly review how to measure distance with dividers, how to make time calculations, and the relationship between time, distance, and speed.

*3.3.1. Measuring Distance*

Distances can be determined using dividers or a ruler, although the former is more commonly employed because it can be used with more precision. The most common way to determine a distance is to set the dividers to the length of the line connecting two points. The dividers are then placed against a scale on the chart to find the actual geographic distance.

In most cases, plotting problems require determining distances in nautical miles. Remember that a minute of *latitude* is equal to one nautical mile. Thus, the distance of a line on a chart can be determined by holding the dividers up to the latitude (vertical) scale on the side of a chart. *Never use the longitude (horizontal) scale to determine the distance between two points.*

As an example, suppose we want to measure the distance between two points on a chart (in this example, between two buoys). First, set the dividers to the two points over which to measure the distance (Figure 3.6). Next, place the dividers against the latitude scale on the chart to find the distance, which is approximately 3.9 nautical miles (Figure 3.7).
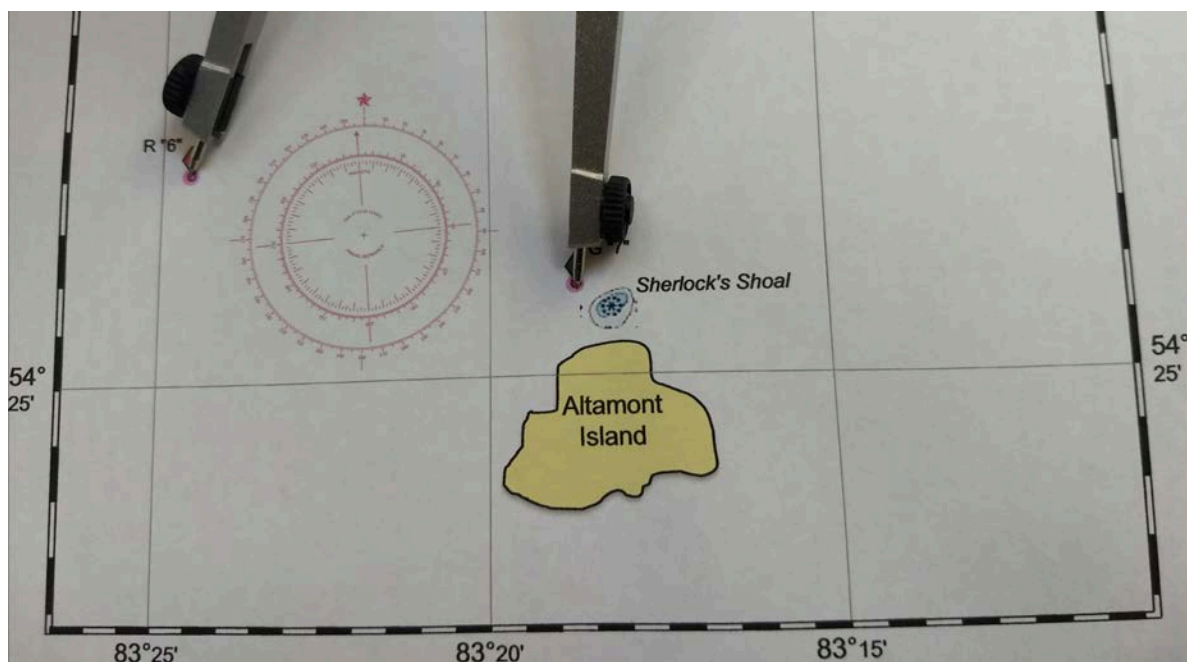
**Figure 3.6.** Placing the dividers on two points.



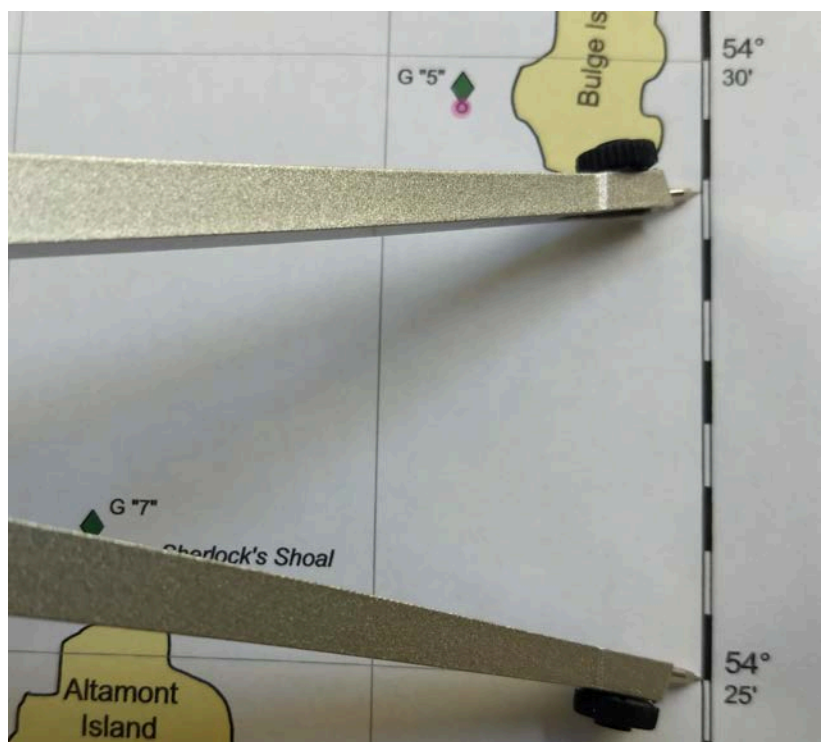**Figure 3.7.** Placing the dividers on the latitude scale.

If the line connecting the two points is larger than the span of the dividers, set the dividers to a span representing a known distance, and then count the number of increments of your compass span in order to cover the length of the line. A tutorial called "How to use dividers" (*http://www.boatsafe.com/navigation/divide1.htm*) also shows this procedure.

*3.3.2. Manipulating Time Values*

For purposes of plotting and navigation, times should be expressed using a 24-hour format, where:

- 12:00 a.m. (midnight) is expressed as 0000
- 12:01-11:59 a.m. is expressed as 0001-1159
- 12:00 p.m. (noon) is expressed as 1200
- 12:01-11:59 p.m. is expressed as 1201-2359

Expressing time in a 24-hour clock greatly simplifies time calculations that are often necessary in order to determine the number of hours and minutes between two events. For example, to determine the elapsed time between 1113 (11:13 a.m.) and 1345 (1:45 p.m.), merely subtract the earlier time from the later time to find the answer (2 hours, 32 minutes):

```
    13 45
  - 11 13
  ---------
     2:32
```

If the minutes value of the ending time is larger than the minutes value of the starting time, we need to "borrow" additional minutes; adding 60 to the ending minutes and subtracting one hour accomplishes this. For example, to determine the elapsed time between 1822 (6:22 p.m.) and 2010 (8:10 p.m.), use the following steps to find the answer (1 hour, 48 minutes):

```
                      -1 +60          19 70
   20 10    →   20 10    →    20̶ 1̶0̶
  - 18 22        - 18 22        - 18 22
  ---------      ---------      ----------
                                   1:48
```

If the starting and end times cross over a day boundary (i.e., the start time is before midnight and the ending time is after midnight), merely add 24 hours to the ending time, for purposes of the calculation. For example, to determine the elapsed time between 2215 (10:15 p.m.) and 0137 (1:37 a.m.), use the following steps to find the answer (3 hours, 22 minutes):

```
                      +24             25
   01 37    →   01 37    →    0̶1̶ 37
  - 22 15        - 22 15        - 22 15
  ---------      ---------      ----------
                                   3:22
```

Finally, it is often necessary to convert the time to minutes. To do this, multiply the hours by 60 and add the minutes, as shown below:

- 2 hours, 32 minutes = 2 × 60 + 32 = 152 minutes
- 1 hour, 48 minutes = 1 × 60 + 48 = 108 minutes
- 3 hours, 22 minutes = 3 × 60 + 22 = 202 minutes

To convert minutes back to hours and minutes, merely divide the minutes by 60; the whole part of the answer is the number of hours and the remainder is the number of minutes. Thus,

- 108 minutes = 108 min ÷ 60 min/hr = 1 hr, 48 min
- 152 minutes = 152 min ÷ 60 min/hr = 2 hr, 32 min
- 202 minutes = 202 min ÷ 60 min/hr = 3 hr, 22 min

### 3.3.3. Distance, Speed, and Time

Many charting problems involve distance traveled, speed made good (i.e., actual speed of the vessel), and the elapsed time to get from one place to another. These problems are generally set up that you know two of these variables and need to find the third.

For purposes of these exercises, the following assumptions and symbols will be used:

- Distance (D) is given in nautical miles (nm)
- Speed (S) is given in nautical miles per hour, or knots[33] (kn[34])
- Time (T) is given in minutes

$$D = T \times S \div 60$$
$$T = D \times 60 \div S$$
$$S = 60 \times D \div T$$
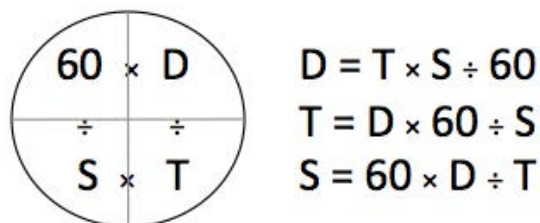
**Figure 3.8.** *60 D ST* mnemonic.

These three variables are related by a formula that can be manipulated depending upon which two factors are known and which one is unknown. A commonly used mnemonic for this formula is "60 D Street," abbreviated *60 D ST* (Figure 3.8). In the figure, find the unknown factor, replace the nearest division operator (÷) with an equal sign (=), and then continue

---

[33] Note that the speedometer on many small recreational boats uses miles per hour (MPH) as the unit of measurement rather than knots. If you perform these calculations using MPH, distances will be in statute miles rather than nautical miles.

[34] The abbreviation *kt* is also commonly used for knots although *kn* is the international standard.

moving in that same direction around the circle to apply the remaining factors and arithmetic operators.

*Example 1:* You have traveled 18 nm (D) in 72 minutes (T). What was the speed made good?

S = 60 × D ÷ T = 60 min/hr × 18 nm ÷ 72 min = 15 kn

*Example 2:* You have been underway for 75 minutes (T) at a speed of 14 knots (S). How far have you traveled?

D = T × S ÷ 60 = 75 min × 14 kn ÷ 60 min/hr = 17.5 nm

*Example 3:* You need to travel 16 nm (D) and can make a speed of 12 knots (S). How long should your trip take?

T = 60 × D ÷ S = 60 min/hr × 16 nm ÷ 12 kn = 80 min = 1 hr 20 min

A *nautical slide rule* (Figure 3.9) can aid the mariner to quickly perform these calculations.



**Figure 3.9.** Nautical slide rule.

## 3.4. Plotting Problems

The paragraphs below will introduce a number of routine plotting problems and the methods by which they can be solved. Keep in mind that when trying to solve a navigational problem,

you need to first determine what it is you are trying to find out and what pertinent information you already know or need in order to solve the problem. You can ignore irrelevant facts.[35]

Charting tasks covered in this section include:

1. Finding latitude and longitude
2. Plotting a position
3. Finding a true bearing and compass course
4. Finding distance and speed made good
5. Estimating time of arrival
6. Dead reckoning
7. Finding set and drift
8. Plotting a course with known set and drift
9. Calculating ETA with known set and drift
10. Obtaining a fix with lines of position
11. Getting a running fix
12. Doubling the angle off the bow

In the problems below, pay careful attention to the course heading, which might be expressed as degrees true (T), magnetic (M), or per steering compass (C). Remember that all headings taken from a chart are true whereas headings that will be used by the vessel's compass are per steering compass.

*For the examples in this section, make the assumption that it is the year 2002. According to the compass rose on the chart, the variation was 4°15'W in 1985 with an annual decrease of 8'; after 17 years, the variation would have decreased by 2°16' to be approximately 2°W.*

*Similarly, the following deviation table will be used for all examples:*

| Heading | Deviation | Heading | Deviation | Heading | Deviation |
|---------|-----------|---------|-----------|---------|-----------|
| 0° | 1°E | 120° | 1°E | 240° | 2.5°W |
| 30° | 1.5°E | 150° | 0° | 270° | 2°W |
| 60° | 2°E | 180° | 1°W | 300° | 0° |
| 90° | 3°E | 210° | 2°W | 330° | 0.5°E |

A number of abbreviations and notational symbols will be used on the charts in this section; these will be explained as introduced. Appendix D provides a Navigator's Quick Reference Card[36] with a summary of the notation and abbreviations used here.

Finally, all charts in this section use the sample chart shown in Appendix E. *The chart in Appendix E is wholly fictitious. Do not attempt to relate this chart to anything in the real word.*

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[35] E.g., suppose you know the distance to your destination, course heading, and speed, and are asked to determine how long the trip will take. To solve for time, you need only know distance and speed; heading is irrelevant.
[36] From *http://captnmike.com/2009/10/01/piloting-and-navigators-quick-reference/*

*3.4.1. Finding Latitude and Longitude*

Determining the latitude and longitude from a point on the chart is a fundamental skill and is relatively straightforward. The easiest way to determine latitude is to orient the parallel ruler on a horizontal line on the chart and then "walk" the parallel ruler until it meets the point of interest and lines up with the chart's horizontal scale; the latitude can be read from the scale. Longitude can be found in a similar way except that you line up the parallel ruler along a vertical line on the chart.
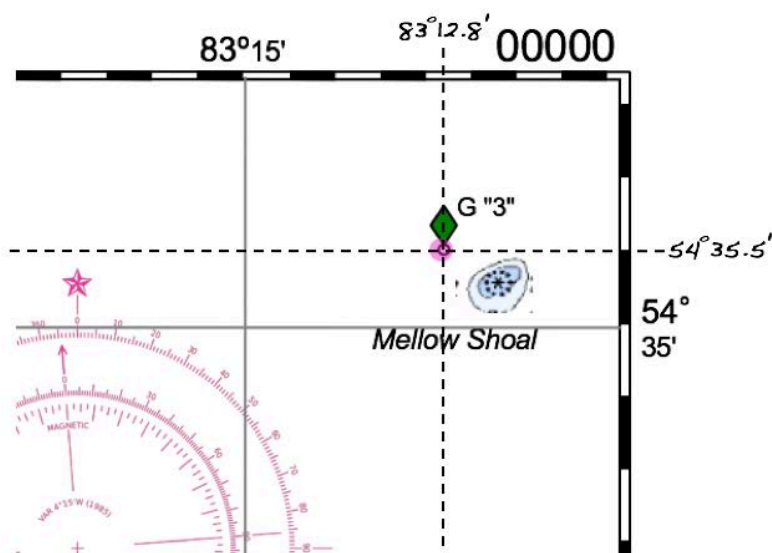


**Figure 3.10.** Finding latitude and longitude.

Figure 3.10 shows an example of this process. In order to find the position of green buoy #3 on the chart, start by positioning the parallel ruler through the horizontal line at 54°35'N and then walk the ruler to run through the buoy's position and the horizonal scale. Next, position the parallel ruler through the vertical line at 83°15' and walk the ruler to run through the buoy and the vertical scale. The lines show the position of the buoy to be 54°35.5'N, 083°12.8'W.

If the position of interest is further from the edge of the chart than the length of the parallel ruler, you can find the latitude and longitude by employing dividers. Line up the ruler with any vertical or horizontal line on the chart, move to the position to measure, and use the dividers to see how far you are from the line. Then, use the dividers on the vertical or horizontal scale to find the latitude or longitude, respectively.

The video titled "Measuring Lat and Long w/ Dividers" (*http://www.youtube.com/watch ?v=K02gFTAz5Mo*) also shows a nice demonstration of this technique.

*As an aside, note that this chart does not specifically indicate whether the location is north or south of the Equator, or east or west of the Prime Meridian. You can determine this information, however, from the context of the latitude and longitude markings on the chart. Remember that*

*charts are always oriented with true north towards the top. When looking at this chart, notice that the minutes on the vertical scale increase going from bottom to top; this means that this chart is in the north latitudes. Similarly, the minutes along the horizontal scale are increasing from right to left, meaning that the chart is in the western longitudes.*

*3.4.2. Plotting a Position*

Plotting a position from latitude and longitude is the opposite of determining those coordinates. In this case, you are given the latitude and longitude, and need to find out where you are on the chart. This is accomplished much like the steps above.
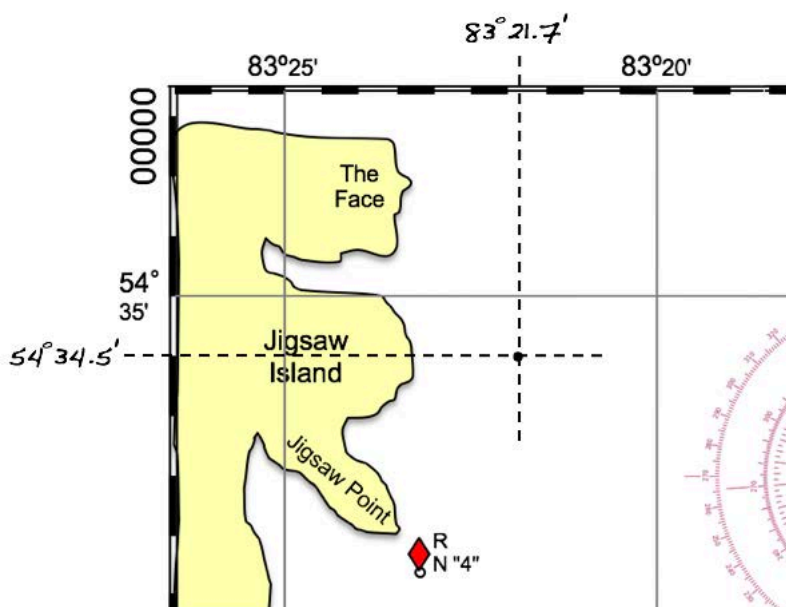


**Figure 3.11.** Plotting position.

Suppose you need to find position 54°34.5'N, 083°21.7'W on the chart. Use your parallel ruler to mark a line at the proper line of latitude and another at the proper line of longitude; the intersection of the two lines is your position (Figure 3.11).

*3.4.3. Finding a True Bearing and Compass Course[37]*

When laying out a course on a chart, it is important to remember that **all** headings are relative to true north. There are times when you need to account for variation and deviation – such as when you obtain a magnetic heading from a compass or need to determine what compass heading to steer on your vessel – but plotting routes on a chart are always true.

---

[37] This section describes how to find the compass course knowing an initial point and an intended destination; another term for this is the *intended course*. If you know the two points and want to find the course between them, this is sometimes referred to as the *course made good*, which is the actual course you took between the two points after accounting for compass variance and deviation, wind, tide, current, and other factors. Bowditch (2002) recommends using the phrase *track made good*.

Finding the true heading requires two points, a parallel ruler (or roll plotter), and the compass rose. The procedure is as follows: Find the two points on the chart, draw a line between the points, align the parallel ruler to the line, and walk the parallel ruler to the compass rose.

As an example, suppose you need to plot your course from LAT 54°35.5'N LONG 083°20.5'W to red buoy #4 (Figure 3.12):

1. Find the two points and draw a line between them; this is called the *trackline*.

2. Line up your parallel ruler and "walk" it to the compass rose.

3. Note that your line will intersect the compass rose in two places. To select the proper heading, you need to recall that you started a couple of miles east of The Face and headed towards the buoy; therefore, you know that you will be going roughly southwest, which means that you want to be in the southwest quadrant of the compass rose. Alternatively, if you were at the center of the compass rose, you would be moving down and to the left. In either case, you should see that the line intersects the *outer* compass ring at 211° true.
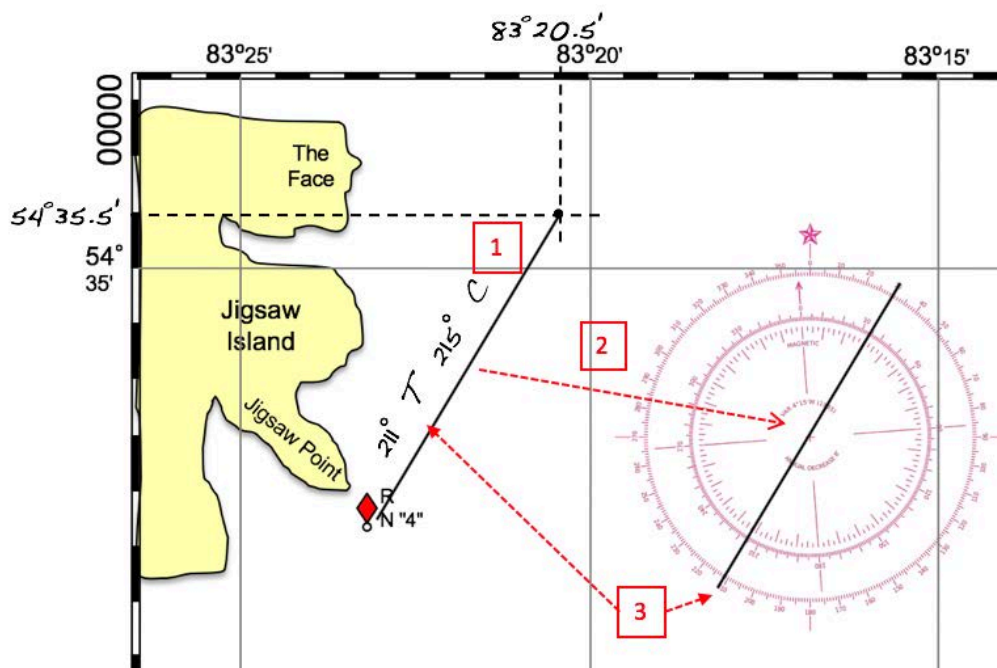


**Figure 3.12.** Finding a true bearing and compass course.

To actually steer this course, you need to convert the compass bearing to a *compass course* to actually steer. To do this, use the *TVMDC +W* calculation. Remember, for this manual the variation is 2°W and the deviation comes from the table in Section 3.4:

T     TRUE       211°

| V | Variation | +2°W | |
|---|-----------|------|---|
| M | MAGNETIC | 213° | |
| D | Deviation | +2°W | (Deviation is 2°W for 210° magnetic) |
| C | COMPASS | 215° | |

### 3.4.4. Finding Distance and Speed Made Good

As described in Section 3.3.1, measuring distance is a job for the dividers. To measure the distance between the two points above, merely place the two ends of the dividers on the two points. Then, find a convenient location on the *vertical (latitude)* scale and measure the distance. In this case, the two points are approximately 3.3 nautical miles apart (Figure 3.13).
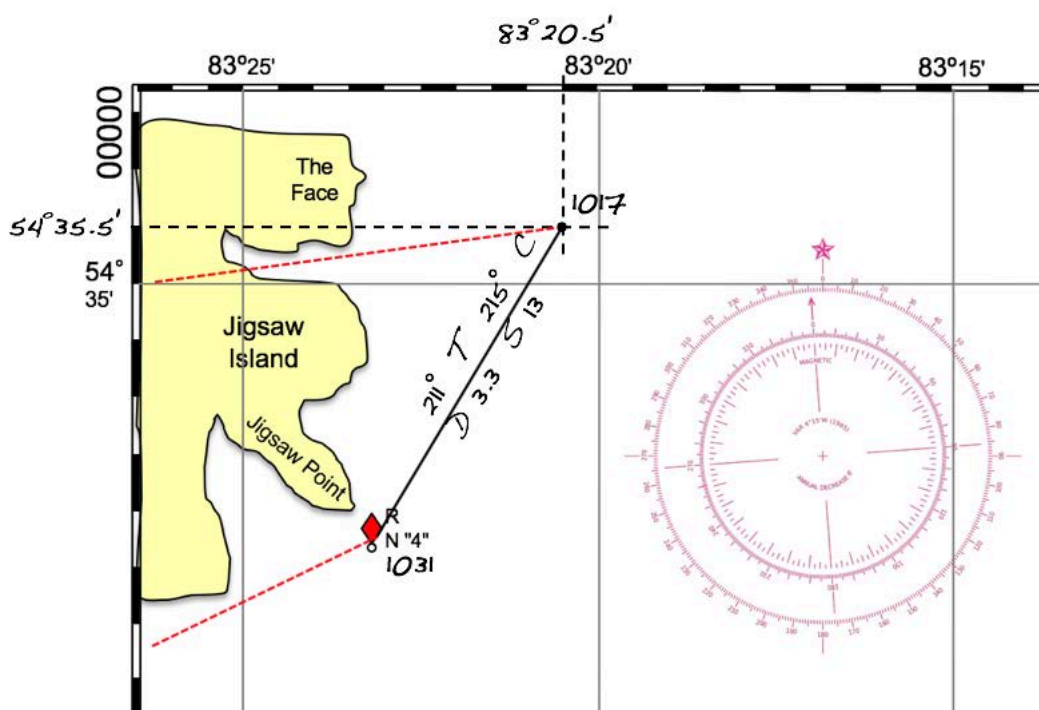


**Figure 3.13.** Finding distance and speed made good.

Determining the speed made good means to calculate your speed over some distance. As shown in Section 3.3.3, use the *60 D ST* formula to calculate speed if distance and elapsed time are known. In this example, the trip started at 1017 and the red buoy was reached at 1031; thus, the elapsed time is 14 minutes. Applying the formula to find speed, we get:

S = 60 × D ÷ T = 60 min/hr × 3.3 nm ÷ 14 min = 14.1 kn

### 3.4.5. Estimating Time of Arrival

Estimating the time of arrival at a destination is another time-speed-distance problem. In Figure 3.14, we leave the mouth of the inlet south of Jigsaw Point and would like an estimated time of

arrival (ETA) at the small bay to the west of Bulge Island, assuming that we plan on making a speed of 10 kn.

1. The start time is 1452.

2. The trackline on the chart shows that the distance is 5.4 nm. Knowing distance and speed, we can solve for time:

$$T = 60 \times D \div S = 60 \text{ min/hr} \times 5.4 \text{ nm} \div 10 \text{ kn} = 32 \text{ min}$$

3. The ETA is 32 minutes after we started, or 1524.
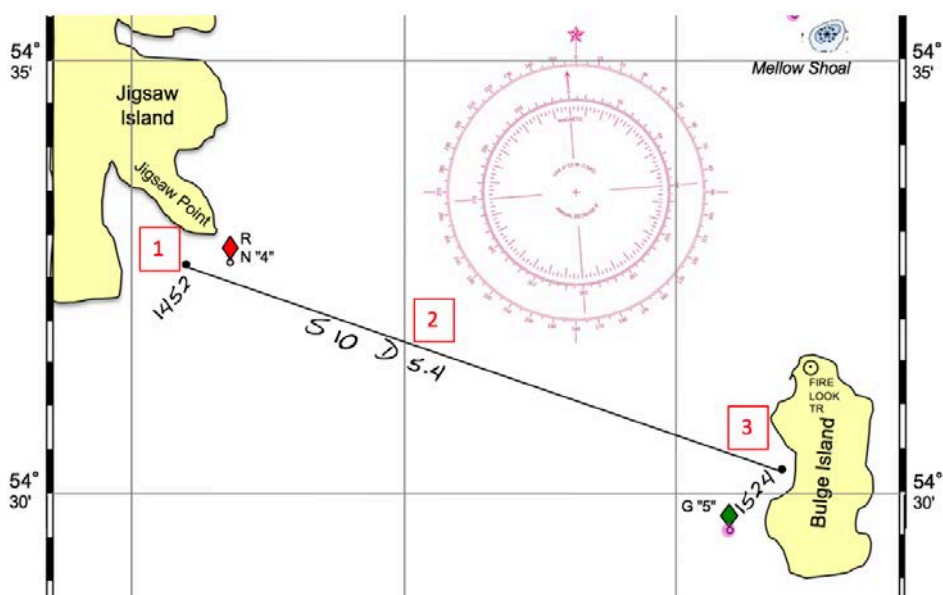


**Figure 3.14.** Estimating time of arrival.

### 3.4.6. Dead Reckoning

Dead reckoning is a method by which a vessel's position can be estimated when the starting position, speed, course, and elapsed time are known. In this example (Figure 3.15), the starting position is just off the most westerly point of Altamont Island at 1554. The vessel is heading on a course of 330° T at a speed of 15 kn. What is the vessel's position at 1615?

1. Create a trackline using the initial point and course. (The triangle around the starting point indicates that this is a known position.)

2. The second point on the trackline can be estimated given the starting point, course, and distance. The distance can be calculated using the *60 D ST* formula because the speed and elapsed time (21 minutes) are known:

$$D = T \times S \div 60 = 21 \text{ min} \times 15 \text{ kn} \div 60 \text{ min/hr} = 5.3 \text{ nm}$$

3. Plot the latitude (54°28.6'N) and longitude (083°23.9'W) of the estimated position. (The arc around the point indicates that this is a dead reckoning estimate.)

Dead reckoning is a crude, but effective, estimation technique. It does not account for – but helps us measure – the effects of winds, tides, and currents, a subject that will be discussed in the next two sections.
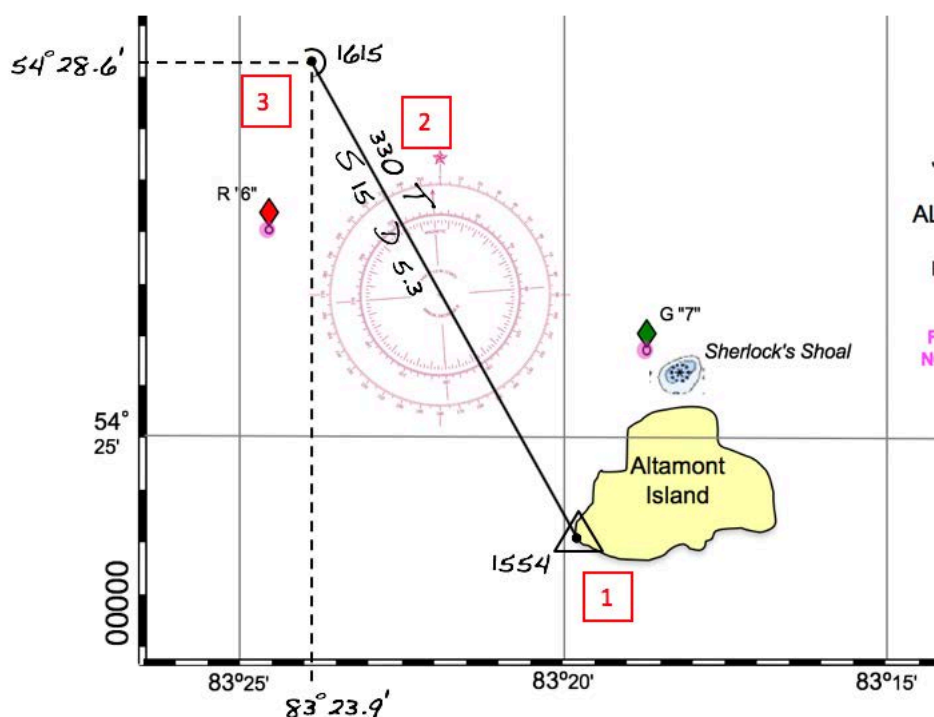


**Figure 3.15.** Dead reckoning.

### 3.4.7. Finding Set and Drift

Dead reckoning provides an estimated position based upon speed and heading, assuming seas that have neither wind, tide, nor current. Much more precise measures are available for determining the actual position, such as using a GPS or taking fixes from known points on land. Combining dead reckoning estimates and precise measures, however, allows for the calculation of the effect of wind, tides, and current and, armed with that information, for determining a more effective choice of heading to efficiently get to an intended destination.

The *set and drift* refers to the effect of wind and seas on the actual course that a vessel takes. This effect can be measured by comparing the estimated position based upon dead reckoning

and the actual position based upon some more precise means. *Set* refers to the direction of the sea's effect and *drift* refers to the speed.[38] The set and drift process is shown in Figure 3.16:

1. A dead reckoning position is determined to be LAT 54°28.6'N LONG 083°23.9'W at 1615.

2. The actual position is found to be (54°28.0'N, 083°24.6'W) by GPS.

3. The trackline from the estimated position towards the actual position shows the direction (set) to be 218° true and the distance to be 0.8 nm. Using the *60 D ST* formula (with D = 0.8 nm and T = 21 min), we find the speed (drift) to be 2.2 kn.

4. If you were to draw a trackline from the initial position to the actual position, you would find that you traveled on a course of 322° true (i.e., the Course Made Good) and traveled a distance of 4.9 nm at a speed of 14 kn (i.e., the Speed Made Good).
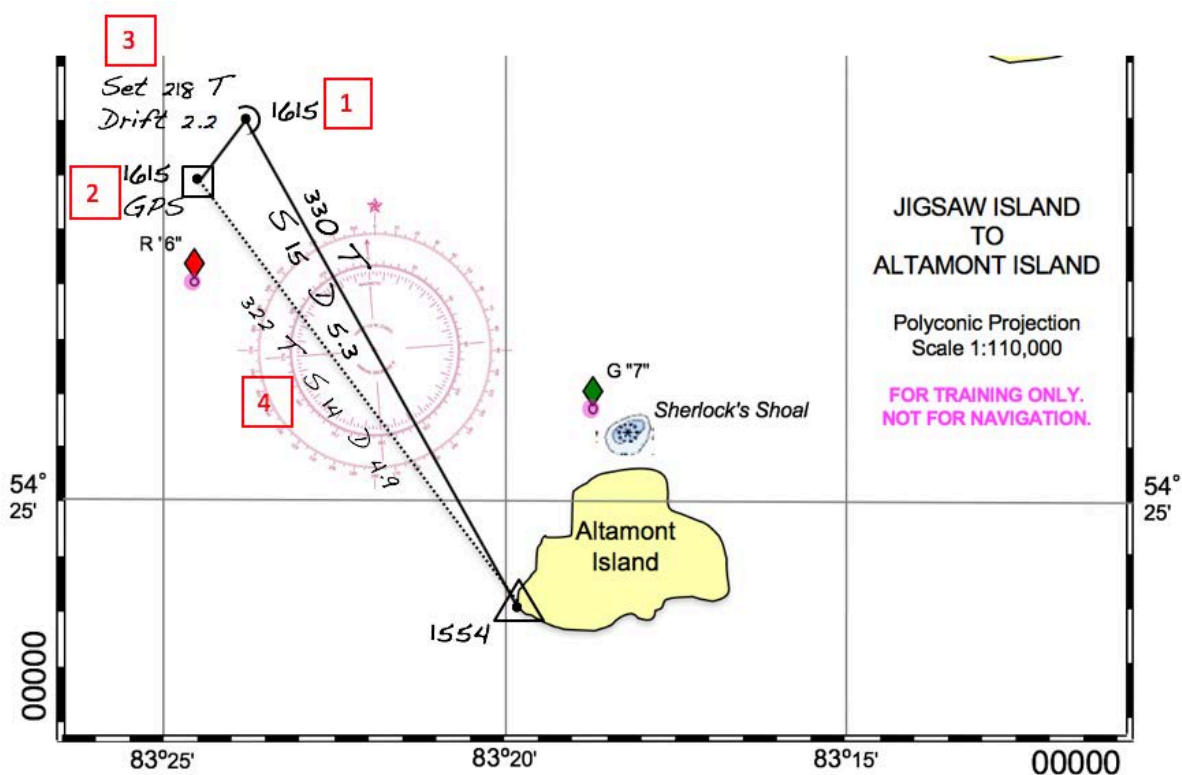


**Figure 3.16.** Determining set and drift.

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[38] Without getting too much into the topic of vector analysis, some readers might have already recognized that a trackline is a vector. In physics, a vector is a line that has both direction (e.g., heading) and magnitude (e.g., distance). Adding the two vectors of a dead reckoning trackline and "set and drift" yields the actual position.

*3.4.8. Plotting A Course With Known Set and Drift*

Knowing the set and drift prior to plotting a course can allow a navigator to determine the most direct course to a destination, also known as the *point to aim (PTA)*. In this example, we wish to plot a course from a position near the base of Jigsaw Point to a dive site approximately two miles east of Altamont Island (Figure 3.17). In this case, we plan on making a speed of 5 kn and there is a known current of 1.5 kn at 085° true.

1. To plot the course accounting for set and drift, start by drawing a trackline between the starting position (labeled *A*) and the intended ending position (denoted by the dive flag). This will be a course of 137° true for a distance of 6.4 nm.

2. Draw a trackline representing the set and drift from point *A* for a distance representing one hour of drift (i.e., 1.5 nm). Label the end point of that line *B*.
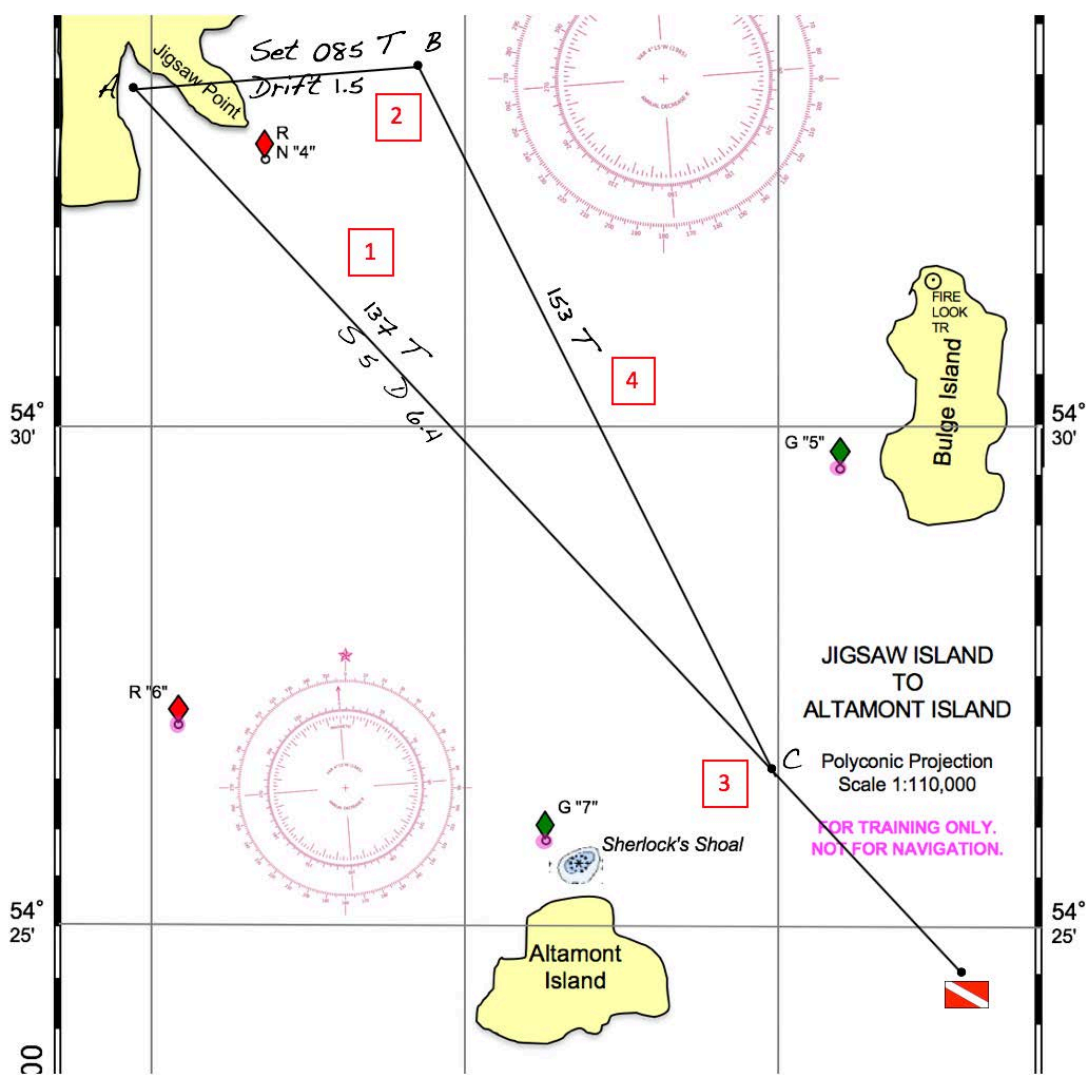


**Figure 3.17.** Plotting with known set and drift.

3. On the original trackline, draw a point where the vessel would be after one hour; label this point *C*. This corresponds to the fact that we drew a one-hour set-and-drift trackline because using an hour is easy for calculations. Since the vessel's speed 5 kn, it will travel 5 nm in one hour.

4. Draw a line connecting points *B* and *C*. Determine the heading of that line to find the most direct course to make good in order to arrive at the destination without constantly having to correct for the sea's effects. In this case, this results in a course of 153° true. Convert this to a compass course using the *TVMDC +W* calculation:

| T | TRUE | 153° | |
|---|------|------|---|
| V | Variation | +2°W | |
| M | MAGNETIC | 155° | |
| D | Deviation | 0° | (Deviation is 0° for 150° magnetic) |
| C | COMPASS | 155° | |

### 3.4.9. Calculating ETA With Known Set and Drift

In the previous section, we calculated the actual course to steer in order to accommodate set and drift due to wind, current, and/or other factors. We're going to look at this problem again, now considering the impact of set and drift on calculating the estimated time of arrival at the destination. **WARNING: Some new arithmetic ahead!**

Refer once again to Figure 3.17. As noted above, point C is the distance we would have traveled from point A in one hour based upon dead reckoning plotting. In this case, point C is 5 nm from point A since our speed is 5 kn.

Note, however, that because we are accounting for set and drift, we are actually traveling the distance between point B and point C, which is a distance of 4.2 nm. Thus, at 5 kn, we would cover this distance in 50 minutes.[39]

If we divide the actual amount of time (50 min) by the estimated amount of time (60 min), we obtain the fraction 0.8333. Therefore, the ETA using the route that accommodates set and drift is going to be 0.8333 times the ETA using dead reckoning.

Back to the original problem, the distance between point A and the intended destination on the dead reckoning plot is 6.4 nm; at 5 kn, the ETA would be 77 min after departure. When accounting for set and drift, the destination is 0.8333 × 6.4 = 5.4 nm and, at 5 kn, the ETA will be 65 min after departure.

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[39] You can confirm this using the 60 D ST formula where D = 4.2 nm and S = 5 kn.

*3.4.10. Obtaining a Fix With Lines of Position*

A *line of position (LOP)* is a compass bearing taken on a known point. If sightings are taken of two known points, the position of the vessel (fix) can be obtained by finding where the two LOPs intersect. Obtaining a fix using three LOPs uses a similar methodology and is generally more precise because there are three points of reference instead of two. This section will describe obtaining a fix with three LOPs but the process is the same with two.

*In the example in this section, the LOP headings are obtained using a hand-held compass. To convert to true north, we have to correct the magnetic heading by the variation. We can ignore the effects of the vessel itself, however, so deviation will not be an issue.*
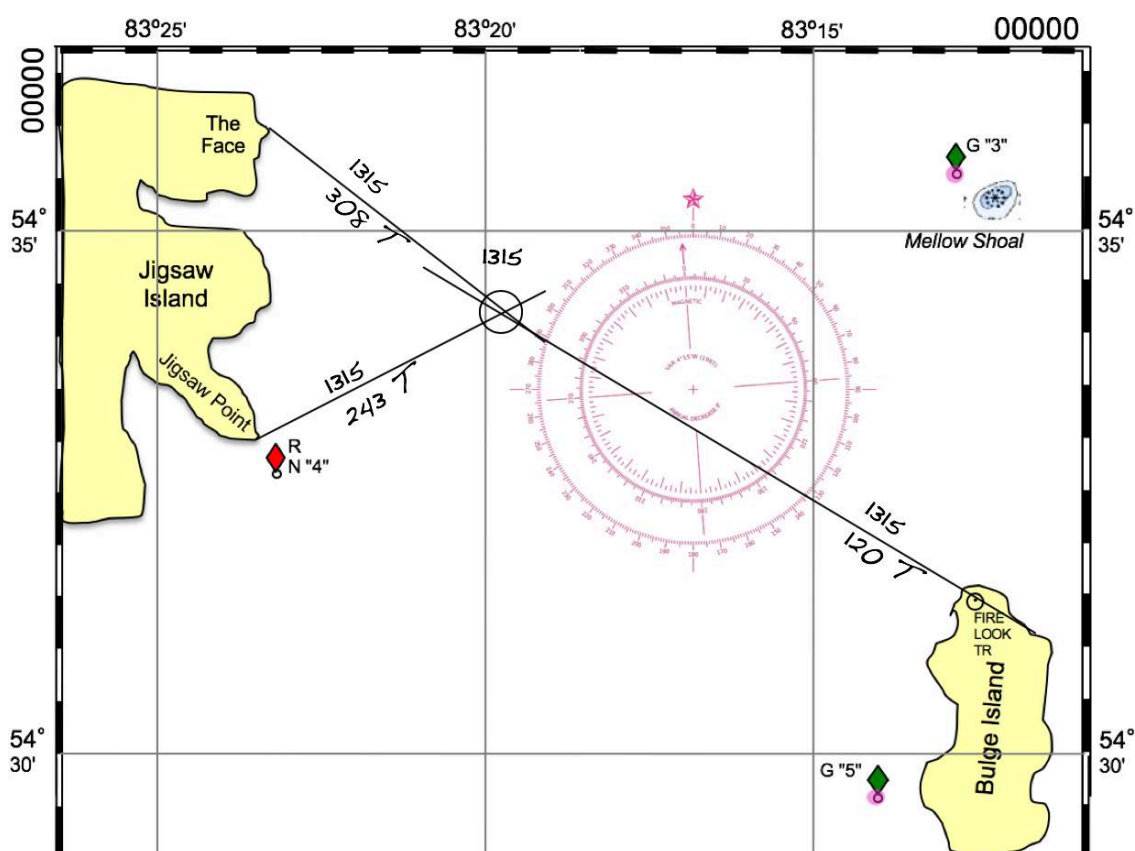


**Figure 3.18.** Obtaining a three-bearing fix.

Suppose our vessel is lying to the east of Jigsaw Island. At 1315, in order to obtain our position, three headings are taken using a hand-held compass. Since the compass gives a reading relative to magnetic north, the headings must be adjusted to true north (variation = 2° W):

| LOP Target | Compass | True |
|---|---|---|
| Tower on Bulge Island | 122°M | 120° T |
| "Nose" of The Face | 310°M | 308° T |
| Tip of Jigsaw Point | 245°M | 243° T |

After converting the readings from the compass to true headings, the LOPs are transferred to the chart, also noting the time that the headings were taken (Figure 3.18). The point at which the three LOPs intersect is the current position.

When taking three bearings, the three LOPs might intersect in such a way as to form a small triangle. In that case, the fix is generally taken as the middle of the triangle. When using this procedure with two bearings, the two LOPs always intersect at one point.

### 3.4.11. Taking a Running Fix

A running fix is a way to obtain an estimate of position while the vessel is underway. The running fix depends on taking two compass readings on one known point at two different times while keeping track of the course and speed of the vessel. Figure 3.19 shows the process of obtaining a running fix based upon two sightings of green buoy #7 north of Altamont Island.
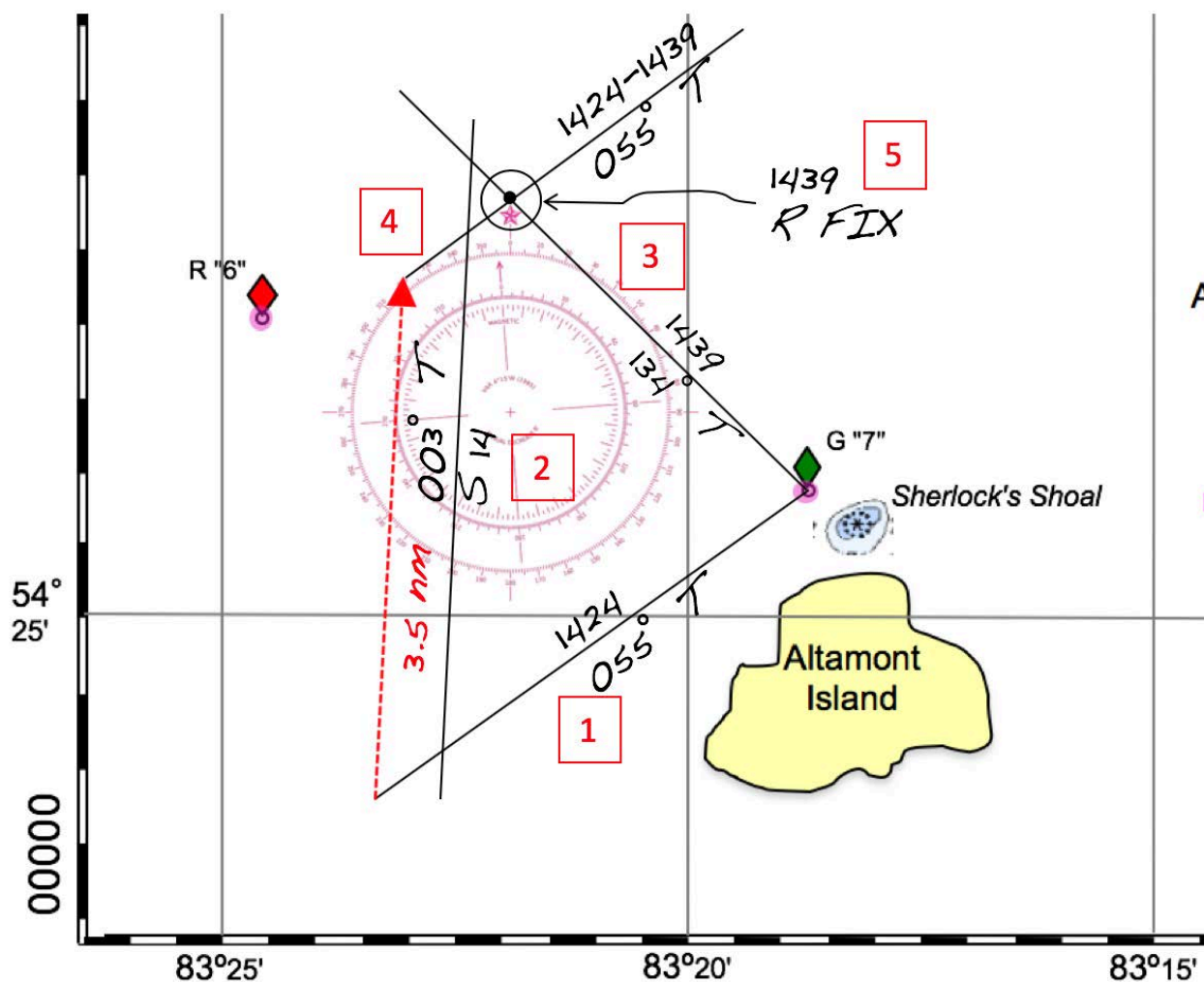


**Figure 3.19.** Taking a running fix.

1. At 1424, the buoy is found to be at a bearing of 057° by handheld compass. Adjusting for variation yields a bearing of 055° true from the vessel. An LOP is drawn to the buoy.

2. At this time, the vessel is running on a heading of 003° true at a speed of 14 kn. Draw a trackline representing this course. (It does not matter where the trackline is drawn as long as it intersects the LOP.)

3. At 1439, another sighting is taken of the buoy by handheld compass. This heading is found to be at 136° magnetic, or 134° true. Draw a second LOP.

4. The two LOP observations were taken 15 minutes apart. Using the *60 D ST* formula, we can determine that the distance travelled in that amount of time at a speed of 14 kn; namely, 3.5 nautical miles. Using the parallel ruler or roll plotter, copy the first LOP (1424) 3.5 nautical miles up the trackline (labeled here as the *1424-1439* LOP).

5. The running fix at 1439 is the point of intersection between the 1439 and 1424-1439 LOP lines.

A running fix works because it is measuring a triangle where one point (the buoy, in this case) is known as well as three angles of a triangle. It is not necessary to know the exact length of the three sides of the triangle, which is why is does not matter where the trackline is drawn. Note that if the trackline in this example were drawn nearer to Altamont Island, the point of intersection would be the same and possibly to the left of the trackline. In fact, the only purpose of the trackline is to provide a reference for "moving" the first LOP to meet the second LOP.

*3.4.12. Double the Angle on the Bow*

Determining your position using the *double the angle on the bow* method is a simple way to estimate position when only a single known point is visible. The method works as follows:

1. When on a given heading, determine the angle to a known point from the bow of the vessel.
2. Maintain speed and heading, and continue forward until the angle to the known point off the bow doubles from the first sighting.
3. Calculate the distance traveled from the first to second sighting (based upon time and speed); that is also the distance that the vessel is from the known point at the last sighted angle.

The geometry behind this method is that of an isosceles triangle, which is a triangle where two sides are of equal length, A (Figure 3.20). Since two angles of the triangle are x° and the total number of degrees in a triangle is 180, the remaining angle is (180-2x)°. This method takes advantage of isosceles triangles so that the sightings taken at the beginning and end of one of

the "sides" of the triangle will represent both the distance traveled as well as the distance from a known point.
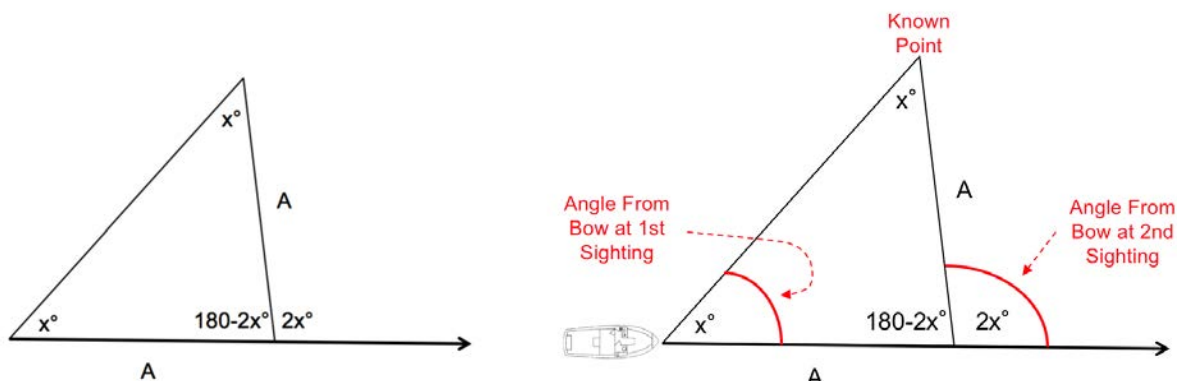


**Figure 3.20.** An isosceles triangle.
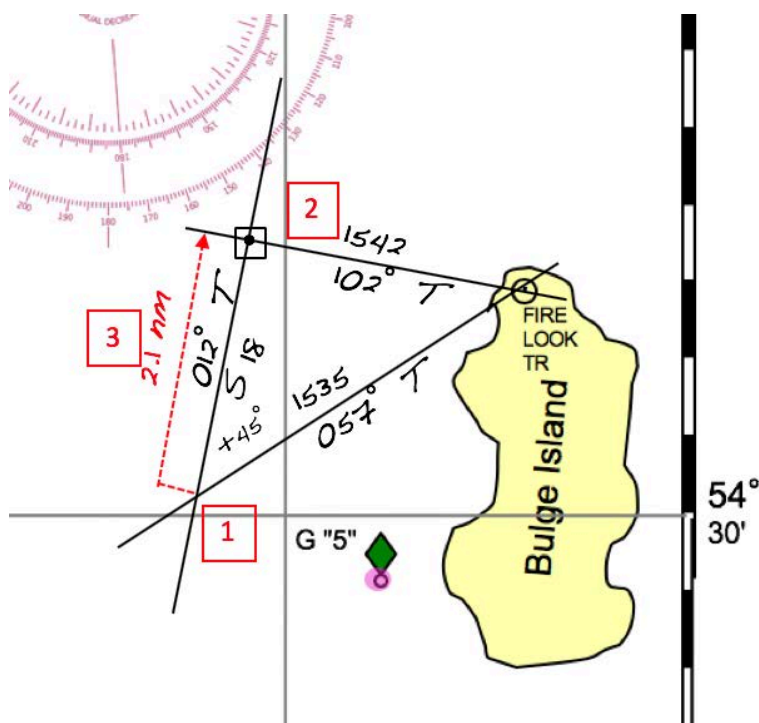


**Figure 3.21.** Double the angle on the bow.

Figure 3.21 shows an example using these steps. Suppose a vessel is on course 012° true at a speed of 18 kn, with Bulge Island to the east.

1. At 1535, the fire lookout tower is found to be at a bearing of 057° true, which is 45° to the east of the boat's current heading.

2. The boat continues at the current speed and heading and, at 1542, the tower appears at a bearing of 102° true (i.e., 90° to the east of the boat's heading).

3. Proceeding 7 minutes (0.12 hours) at a speed of 18 kn means that the boat has traveled approximately 2.1 nm. This also means that the boat's estimated position is 2.1 nm from the lookout tower at a bearing of 102° T (or 258° T from the perspective of the tower).

### 3.4.13. Other Ways in Which to Get a Fix

As described above, two or three LOPs are required in order to obtain a fix. So far in this section, LOPs have been obtained by taking a bearing to a known, fixed object. There are two other methods for obtaining an LOP that are slightly more advanced and, while mentioned here, are not described further.

The first method is to obtain an LOP using a *range*, which means to line up two landmarks that are at a known, fixed position. An LOP using a range does not require a known bearing; the alignment is due to the lining up of the two known points. In general, be careful using an ATON as a point on a range and definitely do not use a buoy; lights are generally good points of reference. Figure 3.22 shows an LOP based upon a range taken by lining up the Fire Lookout Tower on Stave Island and the flashing red light at the cut between Lake Champlain and Malletts Bay (Chart 14782), taken at 1953.
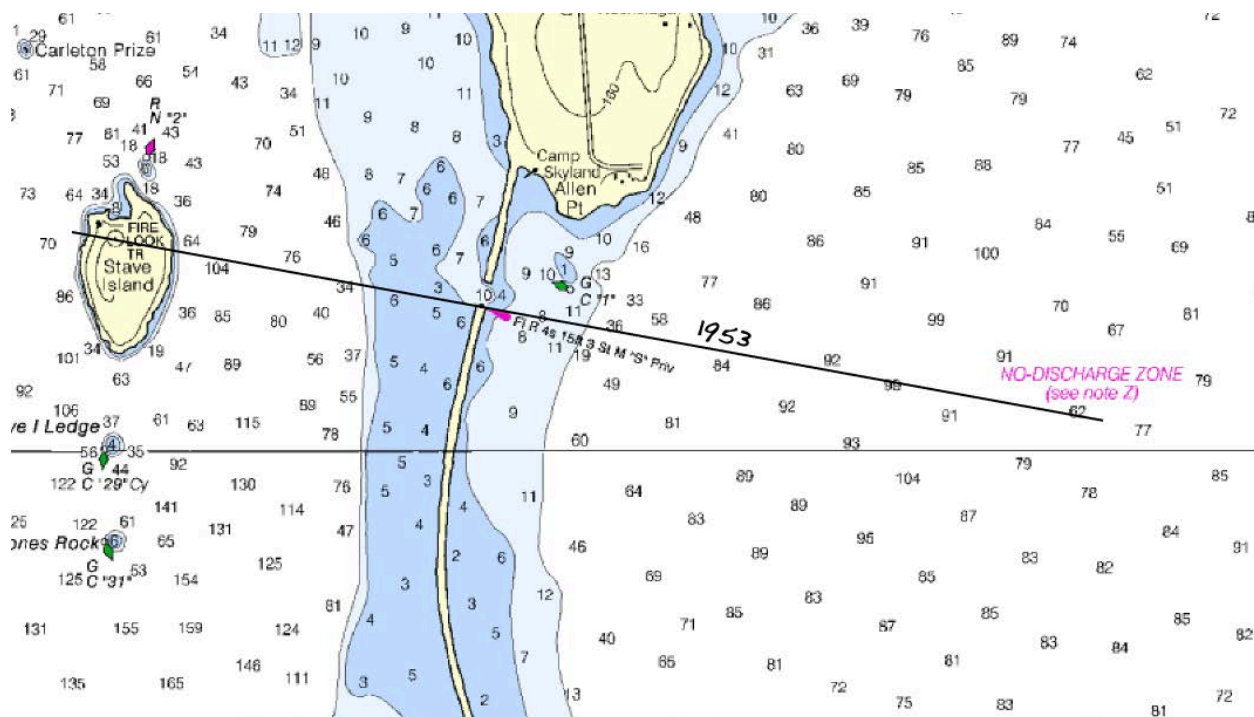


**Figure 3.22.** LOP from a range between a tower and light, from Chart 14782.

The second method is to obtain an LOP based upon the distance from a known point, called taking a *range*. This method requires the ability to determine distance, which might be done using radar, a range finder, or using a sextant (or any device that can determine the distance to an object if the height of the object, such as a lighthouse, is known). Figure 3.23 shows an LOP

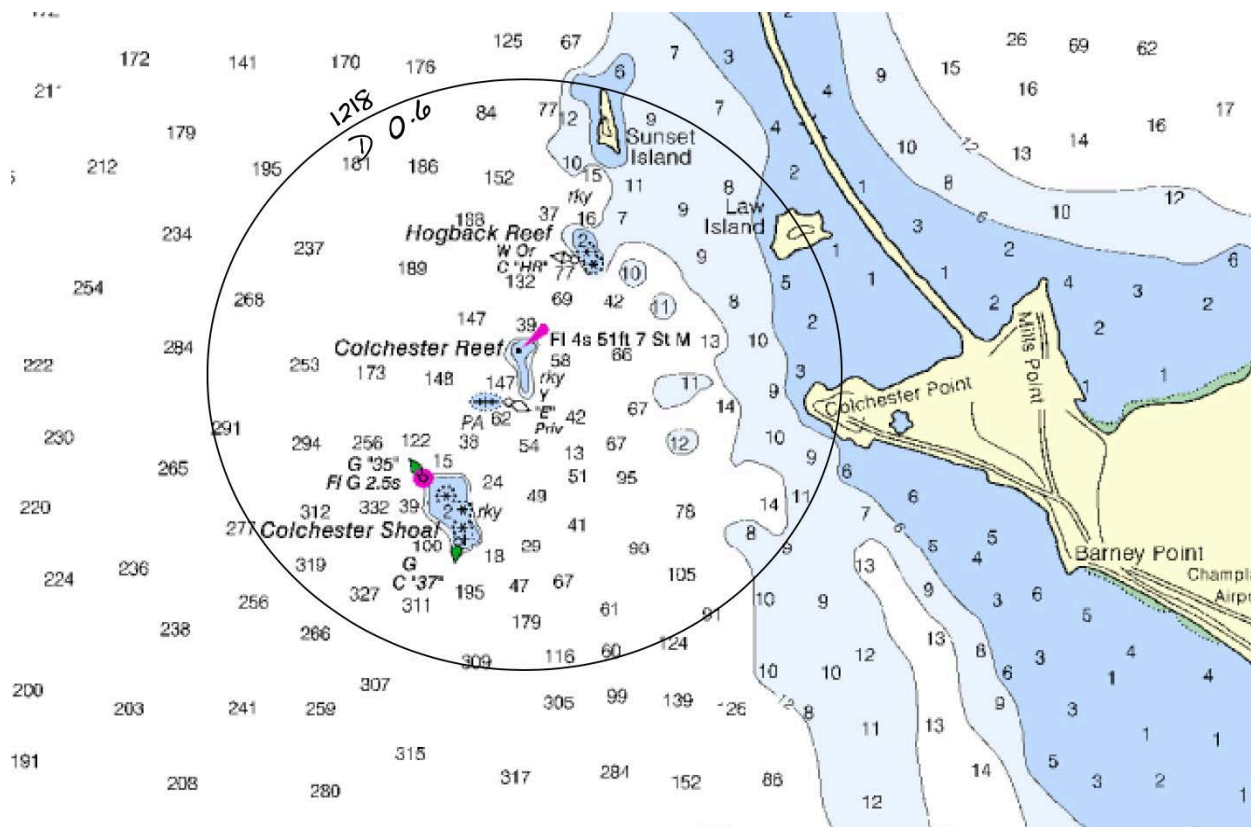taken at 1218, 0.6 nautical miles from the Colchester Reef Lighthouse in Lake Champlain (Chart 14782).



**Figure 3.23.** LOP based on a distance from a known object, from Chart 14782.

Getting a fix still requires finding an intersection between two or three LOPs, but there are three forms of LOP, namely, bearing, range, and distance.

## 3.5. Voyage Planning

Although not specifically a charting, plotting, or navigation problem, voyage planning – i.e., calculating fuel consumption and your vessel's range and endurance – is essential to ensure that you have sufficient fuel in order to make a safe transit. This section will introduce the basic concepts of the speed curve, fuel consumption, range and endurance calculations, and voyage planning.

A *speed curve* is a table showing the relationship between the throttle setting (in revolutions per minute, or RPM) and the boat's speed through water (STW), while a *fuel consumption table* shows the relationship between the throttle setting and the fuel burn rate (in gallons per hour, or GPH). These values can generally be obtained from the boat's manufacturer or from Web sites such as *BoatTEST.com*, although some experts suggest that the boat owner verify the published results themselves. In any case, the relationship between throttle settings, STW, and fuel consumption depends upon a number of factors, including the type of hull (e.g.,

displacement, semi-displacement, or planing), the weight of the boat and engine, the type of engine (e.g., outboard, inboard, horsepower, etc.), the style and size of the propellor, and the type of fuel (e.g., gasoline or diesel). On any given voyage, the weight of the fuel, passengers, and supplies, as well as wind and current, will also affect the actual relationships but the basic tables will provide a good estimate for planning purposes.

Consider, for example, the following speed curve/fuel consumption table and graph (Figure 3.24):

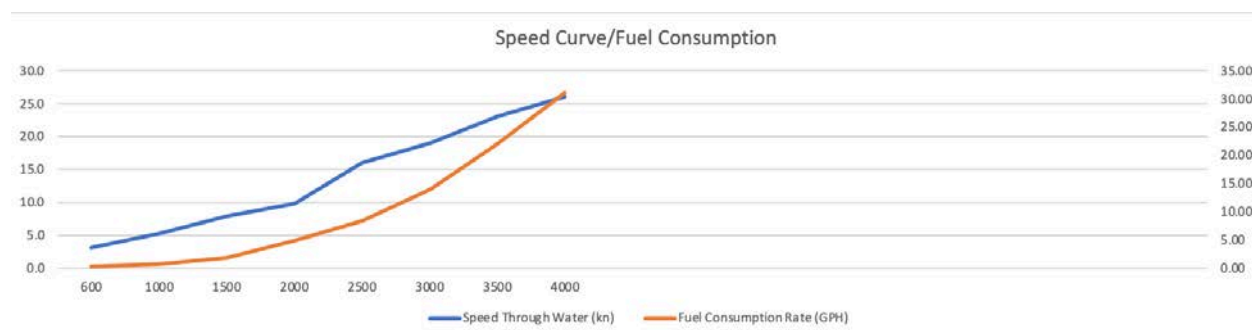| Throttle (RPM) | 600 | 1,000 | 1,500 | 2,000 | 2,500 | 3,000 | 3,500 | 4,000 |
|---|---|---|---|---|---|---|---|---|
| STW (kn) | 3.1 | 5.3 | 7.9 | 9.8 | 16 | 19 | 23 | 26 |
| Fuel Burn Rate (GPH) | 0.3 | 0.7 | 1.9 | 4.9 | 8.4 | 14 | 22 | 31 |



**Figure 3.24.** Sample Speed Curve/Fuel Consumption graph.

A vessel's range and endurance table can be created from the power curve and fuel consumption values by taking into account the fuel capacity of the vessel (or, the amount of fuel that is on board). For planning purposes, it's always a good idea to consider contingencies and leave at least 10% of the fuel in reserve. It's also possible to factor in the effects of a following or foul current. A vessel performance/planning table (Figure 3.25) includes:[40]

- *Speed of advance (SOA):* The actual speed with which the boat goes through the water, taking into account the tide and current; a following current will make you go faster while a foul current will dampen your speed.
- *Fuel Efficiency (nm/gallon)* = SOA (nm/hr) divided by the Fuel Consumption (gallons/hr)
- *Range (nm)* = Fuel Capacity (gallons) multiplied by the Fuel Efficiency (nm/gallon)
- *Endurance (hours)* = Range (nm) divided by the SOA (nm/hr)

This table uses knots and nautical miles as the units of speed and range, respectively. The calculations are identical if miles per hour and statute miles are used instead.

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[40] An Excel version of this worksheet can be downloaded from *https://scuba.garykessler.net/library/PerformanceTable&Graph.xlsx*.

| | | VESSEL PERFORMANCE/PLANNING TABLES | | | | | |
|---|---|---|---|---|---|---|---|
| VESSEL: | Mellow | | | DATE: | 11/05/2020 | | |
| Current (kn): | -1.5 | (positive is following current, negative is foul current) | | | | | |
| Fuel capacity (gallons): | | 240 | | Reserve (%) | 10 | | |
| Throttle Setting (RPM) | Speed Through Water (kn) | Speed of Advance (kn) | Fuel Consumption Rate (GPH) | Fuel Efficiency (nm/gal) | Range (nm) | Endurance (hrs) | |
| 600 | 3.1 | 1.60 | 0.3 | 5.33 | 1152 | 720 | |
| 1000 | 5.3 | 3.80 | 0.70 | 5.43 | 1173 | 309 | |
| 1500 | 7.9 | 6.40 | 1.90 | 3.37 | 728 | 114 | |
| 2000 | 9.8 | 8.30 | 4.90 | 1.69 | 366 | 44 | |
| 2500 | 16.0 | 14.50 | 8.40 | 1.73 | 373 | 26 | |
| 3000 | 19.0 | 17.50 | 14.00 | 1.25 | 270 | 15 | |
| 3500 | 23.0 | 21.50 | 22.00 | 0.98 | 211 | 10 | |
| 4000 | 26.0 | 24.50 | 31.00 | 0.79 | 171 | 7 | |

**Figure 3.25.** Sample Vessel Performance/Planning Table.

| | | | | VOYAGE PLAN | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| VESSEL: | Mellow | | | | DATE: | 11/06/2020 | | | | |
| Description: | Halifax Harbor Marina to Lady P (site 12) | | | | | | | | | |
| Starting Point | End Point | Distance (nm) | Throttle Setting (RPM) | Speed Through Water (kn) | Current (kn) | Fuel Burn Rate (GPH) | Speed of Advance (kn) | Fuel Used (gal) | Time (min) | |
| Marina | BCN 40 Halifax R. | 0.60 | 1500 | 7.9 | 0.0 | 1.90 | 7.9 | 0.14 | 4.6 | |
| BCN 40 | Inlet channel, bouy 1 | 7.30 | 4000 | 26.0 | 0.5 | 31.00 | 26.5 | 8.54 | 16.5 | |
| Bouy 1 | Disappearing Island | 1.30 | 1500 | 7.9 | 1.0 | 1.90 | 8.9 | 0.28 | 8.8 | |
| Disappearing Is. | Mouth of inlet | 1.60 | 4000 | 26.0 | 2.5 | 31.00 | 28.5 | 1.74 | 3.4 | |
| Inlet | Site 12 | 9.80 | 3000 | 19.0 | 0.0 | 14.00 | 19.0 | 7.22 | 30.9 | |
| Site 12 | Mouth of inlet | 9.80 | 3000 | 19.0 | 0.0 | 14.00 | 19.0 | 7.22 | 30.9 | |
| Inlet | Disappearing Island | 1.60 | 4000 | 26.0 | -3.0 | 31.00 | 23.0 | 2.16 | 4.2 | |
| Disappearing Is. | Inlet channel, bouy 1 | 1.30 | 1500 | 7.9 | -2.0 | 1.90 | 5.9 | 0.42 | 13.2 | |
| Bouy 1 | BCN 40 Halifax R. | 7.30 | 4000 | 26.0 | -0.5 | 31.00 | 25.5 | 8.87 | 17.2 | |
| BCN 40 | Marina | 0.60 | 1500 | 7.9 | 0.0 | 1.90 | 7.9 | 0.14 | 4.6 | |
| | Total distance (nm): | 40.6 | | | | Total fuel used (gallons): | | 36.7 | | |
| | | | | | | Total time elapsed (minutes) | | | 134 | |
| | | | | | | Total time elapsed (hour:min) | | | 2:14 | |

**Figure 3.26.** Sample Voyage Plan.

All of this information can be used together to build a voyage planning worksheet. By using the trip's waypoints and distances, coupled with the speed curve and fuel consumption information, estimates of fuel consumption and elapsed time can be produced. The example in Figure 3.26 shows a voyage planning worksheet for a trip from the Halifax Harbor Marina in Daytona Beach, FL to a dive site (Site 12) approximately 9.8 nm offshore from the mouth of Ponce de Leon Inlet. This worksheet also takes current information into account.

Tables such as this allow you to find the throttle setting (and speed) that optimizes time and fuel consumption, based upon your requirements. Let's look at the impact of the throttle setting on just the round-trip leg from the mouth of the inlet to Site 12 and back. In this example, a throttle setting of 3000 RPM yields an estimated total round trip of 134 minutes that consumes 36.7 gallons of fuel. The table below shows what happens when the throttle setting is changed just for this leg:

| Throttle (RPM) | STW (kn) | Total Trip Time (hour:min) | Total Fuel Used (gallons) |
|---|---|---|---|
| 2500 | 16.0 | 2:26 | 32.7 |
| 3000 | 19.0 | 2:14 | 36.7 |
| 3500 | 23.0 | 2:03 | 41.0 |
| 4000 | 26.0 | 1:58 | 45.7 |

As shown, a lower throttle setting of 2500 RPM yields a trip that takes 24% more time than a trip at a throttle setting of 4000 RPM, but consumes 28% less fuel. In general, slower trips consume less fuel but take longer. A wise voyage planner will attempt to balance the requirements of time and fuel usage (and cost!).

**3.6. Summary**

This section has provided an overview of some of the basic charting and navigation tasks that a recreational mariner might need to perform, as well as a very brief introduction to voyage planning. As stated in the introduction, automated devices, particularly marine GPS devices, can perform all of these charting and navigation functions today. Nevertheless, knowing how to perform these tasks will add to your own knowledge and provide a backup to the electronics. It will also add to your confidence and, maybe, your enjoyment of the trip!

**APPENDIX A:**
**Expressing Latitude and Longitude**

There are three common formats with which express latitude and longitude:

- Traditionally, coordinates are written in terms of degrees (°), minutes ('), and seconds ("). This notation (DD°MM'SS") is also called *DMS* format. The Light List, for example, expresses the position of ATONs as DMS coordinates.
- For purposes of charting and plotting, a position is generally expressed in terms of degrees, minutes, and fractions of a minute (DD°MM.MM'). This is also sometimes called *GPS* or *chart* format.
- Some applications require a *decimal* format for latitude and longitude, written as the number of degrees and fractions of a degree (DD.DDD°). This is an easy way, for example, of entering coordinates into software such as Google Maps.

This sections will show how to quickly convert from one format to the other. While there are several Web sites that will convert a latitude or longitude from one notation to another for you,[41] it is useful to understand the arithmetic behind the conversion. The key point to remember is that a degree is composed of 60 minutes and a minute is composed of 60 seconds.

You can convert the number of seconds to a fraction of a minute by dividing seconds by 60 and you can convert the number of minutes to a fraction of a degree by dividing minutes by 60. By way of example, suppose that we have a coordinate expressed in DMS notation as 13°48'12".

**STEP 1:** 12" can be expressed as a fraction of a minute by dividing by 60: 12"/60 = 0.2'
 This coordinate can now be expressed as 13°48.2' in GPS/chart format.

**STEP 2:** 48.2' can be expressed as a fraction of a degree by dividing by 60: 48.2'/60 = 0.80333°
 This coordinate can now be expressed as 13.80333° in decimal format.

Conversely, fractional parts of degrees and minutes can be expressed as whole minutes or seconds, respectively, by multiplying the fractional part by 60. As another example, suppose we have a coordinate expressed in decimal format as 43.68892°.

**STEP 1:** 0.68892° can be expressed in minutes by multiplying by 60: 0.68892° x 60 = 41.3352'
 This coordinate can now be expressed as 43°41.3352' in GPS/chart format.

**STEP 2:** 0.3352' can be expressed in seconds by multiplying by 60: 0.3352' x 60 = 20.112"
 This coordinate can now be expressed as 43°41'20" in DMS format.

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[41] One such site is *http://www.csgnetwork.com/gpscoordconv.html*. There are also apps available for Android and iOS platforms. A spreadsheet and Perl program for performing these calculations can also be found at *http://www.garykessler.net/software#latlong*.

The sections below have three more specific examples showing how to move between the various coordinate formats.

**EXAMPLE 1: Converting DMS to Decimal and GPS/Chart Notation**

The coordinates of the Ponce de Leon Inlet Lighted Bell Buoy 2 – the local sea buoy, welcome buoy, and farewell buoy – is listed in the USCG District 7 Light List (LLNR 9515) as (29-04-46.031N, 080-53-29.015W), as shown below. What is the latitude and longitude in GPS/chart and decimal formats?

| | Ponce de Leon Inlet | | | | |
|---|---|---|---|---|---|
| 9515 | - *Lighted Bell Buoy 2* | 29-04-46.031N | Fl R 2.5s | 5 | Red. |
| 615 | | 080-53-29.015W | | | |

*DMS Format: 29°04'46.031"N, 080°53'29.015"W*

Convert seconds to fractions of a minute by dividing the seconds by 60:
46.031"/60 = 0.767183'          29.015"/60 = 0.483583'

*GPS/Chart Format: 29°04.767183', -080°53.483583'*

Convert minutes to fractions of a degree by dividing the minutes by 60:
*04.767183'/60 = 0.079453°          53.483583'/60 = 0.891393°*

*Decimal Format: 29.079453°, -080.891393°*

**EXAMPLE 2: Converting Decimal to DMS and GPS/Chart Notation**

Shulamit's Eilat Diving Adventures can be found by entering the decimal coordinates (29.554194, 34.960732) into Google Maps. What is the latitude and longitude in GPS/chart and DMS formats?

*Decimal Format: 29.554194°, 034.960732°*

Convert fractions of a degree to minutes by multiplying the fraction by 60:
0.554194° x 60 = 33.25164'          0.960732° x 60 = 57.64392'

*GPS/Chart Format: 29°33.25164', 034°57.64392'*

Convert fractions of minutes to seconds by multiplying the fraction by 60:
0.25164' x 60 = 15.10"          0.64392' x 60 = 38.63"

*DMS Format: 29°33'15.1"N, 034°57'38.63"E*

**EXAMPLE 3: Converting GPS/Chart Notation to DMS and Decimal**

The position of the wreck of the Horse Ferry in Burlington Bay – the only known wreck of a horse-powered ferry in North America[42] – is found on a chart at (44°29.12000'N, 073°14.58000'W). What is the latitude and longitude in DMS and decimal formats?

*GPS/Chart Format: 44°29.12000', -073°14.58000'*

Convert minutes to fractions of a degree by dividing the minutes by 60:
29.12000'/60 = 0.485333°          14.58000'/60 = 0.243000°

*Decimal Format: 44.485333°, -073.243000°*

Convert fractions of minutes to seconds by multiplying the fraction by 60:
0.12000' x 60 = 7.2"          0.58000' x 60 = 34.8"

*DMS Format: 44°29'07.2"N, 073°14'34.8"W*

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[42] See Kessler, G.C. (2016, Fall). The Wrecks of Lake Champlain. *MAHSnews, The Newsletter of the Maritime Archaeological and Historical Society*, *27*(2), 5-8. https://scuba.garykessler.net/library /WOLC_MAHS_2016%20Fall.pdf

**APPENDIX B:**
**Mercator and Polyconic Projections**

Maps and charts are drawn on a two-dimensional plane, such as a piece of paper or GPS screen. They are, however, a representation of a three-dimensional object, namely, the Earth. There are a number of ways to present the picture of the globe in two dimensions and these are called *projections*.
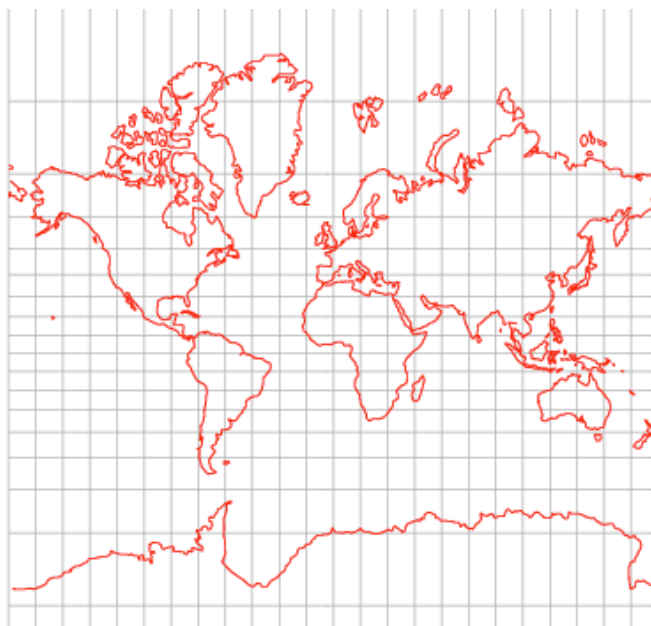


**Figure B.1.** Mercator projection.[43]

Mercator projections (Figure B.1) are the oldest way of representing navigation maps and charts (developed by Gerardus Mercator in 1569). Mercator projections represent latitude (parallels) and longitude (meridians) as straight lines that intersect at right (90°) angles. This is not a true representation of the parallels and meridians on the globe, of course; lines of latitude are, indeed, concentric circles that have smaller and smaller circumferences as they approach the poles whereas lines of longitude are all the same length.[44]

Most nautical charts are drawn using a Mercator projection. On any particular chart, the distances between meridians are equal but the distances between parallels increase progressively from the Equator toward the poles. One advantage of a Mercator projection is that a constant course between any two points on the chart can be represented as a straight line, called a *rhumb line* (or *loxodrome*). This property of the Mercator projection is the primary reason that it is preferred for use with nautical charts.

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[43] http://mathworld.wolfram.com/MercatorProjection.html
[44] It is because lines of longitude are the same length that distance is always measured on the vertical scale of a nautical chart using Mercator projections. The horizontal scale shows degrees of longitude, which vary in distance depending upon how far north or south they are.

Polyconic projections (Figure B.2), first described in the 1825 by Ferdinand Rudolph Hassler, look down on a flat representation of the globe with the Equator and Prime Meridian intersecting at right angles in the middle. With this type of projection, parallels of latitude appear as nonconcentric arcs, and meridians of longitude appear as curved lines that converge at the poles. The scale is correct along any parallel and along the central meridian of the chart. Along other meridians, the scale increases as distance increases from the central meridian. Polyconic projections are used on most U.S. nautical charts for the Great Lakes and its connecting waterways.
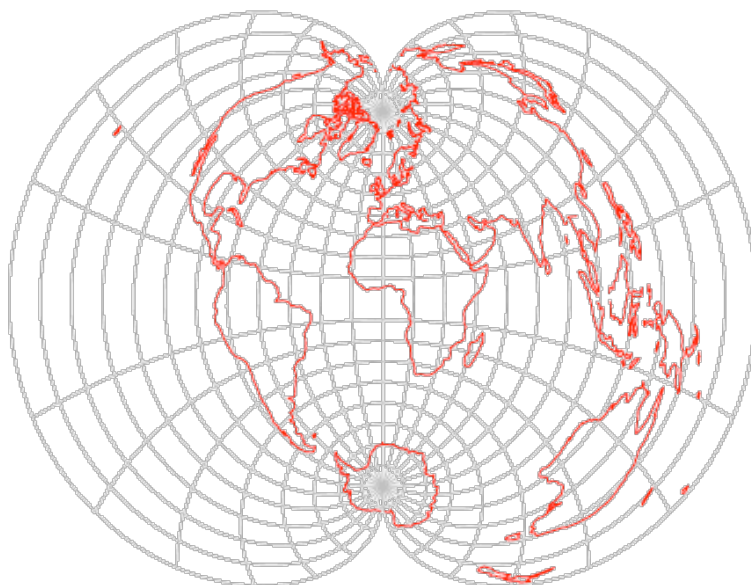


**Figure B.2.** Polyconic projection.[45]

This information is included here because it is pertinent to charting. That said, for most nautical charts used by the recreational boater, it does not make that much difference because the distances covered by the charts are so small.

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[45] http://mathworld.wolfram.com/PolyconicProjection.html

**APPENDIX C:**
**The Length of a Degree**

Several places in this document state that a degree of latitude is equal to 60 nautical miles whereas the linear distance of a degree of longitude varies with latitude. Indeed, a degree of longitude is roughly 60 nautical miles only at the Equator, getting shorter as the latitude approaches the poles.

If the Earth was a perfect sphere, the linear distance represented by a degree of latitude or longitude would be relatively easy calculations using simple trigonometry. The National Geospatial-Intelligence Agency (NGA) has a set of formulas to calculate these linear distances that are a bit more complex, to accommodate the actual globe that we call home:

> length of 1° latitude (meters) = 111132.92 + (-559.82 × cosine (2×lat)) + (1.175 × cosine (4×lat)) + (-0.0023 × cosine (6×lat))
>
> length of 1° longitude (meters) = (111412.84 × cosine (lat)) + (-93.5 × cosine (3×lat)) + (-0.118 × cosine (5×lat))

These formulas are the basis for the "Length of a Degree of Latitude and Longitude Calculator" Web sites at *https://msi.nga.mil/msisitecontent/staticfiles/calculators/degree.html* and *http://www.csgnetwork.com/degreelenllavcalc.html*, and yield the following table:

| Latitude | One degree of latitude | | | One degree of longitude | | |
|---|---|---|---|---|---|---|
| | sm | nm | km | sm | nm | km |
| Equator (0°) | 68.71 | 59.71 | 110.57 | 69.17 | 60.11 | 111.32 |
| 10° | 68.73 | 59.72 | 110.61 | 68.13 | 59.20 | 109.64 |
| 20° | 68.79 | 59.78 | 110.70 | 65.02 | 56.50 | 104.65 |
| 30° | 68.88 | 59.86 | 110.85 | 59.95 | 52.10 | 96.49 |
| 40° | 68.99 | 59.95 | 111.04 | 53.06 | 46.11 | 85.39 |
| 50° | 69.11 | 60.06 | 111.23 | 44.55 | 38.71 | 71.70 |
| 60° | 69.23 | 60.16 | 111.41 | 34.67 | 30.13 | 55.80 |
| 70° | 69.32 | 60.24 | 111.56 | 23.73 | 20.62 | 38.19 |
| 80° | 69.38 | 60.29 | 111.66 | 12.05 | 10.47 | 19.39 |
| Poles (90°) | 69.40 | 60.31 | 111.69 | 0 | 0 | 0 |

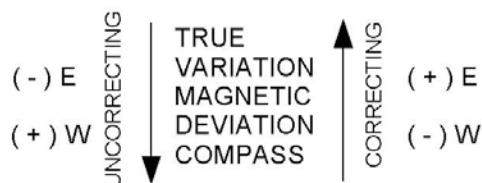Key: sm = statute miles; nm = nautical miles; km = kilometers

To calculate the distance between two points, given their latitude and longitude, see *https://www.nhc.noaa.gov/gccalc.shtml* (and many other similar sites). Meeus (1999) provides a wonderful set of formulas related to calculating many things related to calendars, time, and the planets.

# APPENDIX D:
# Navigators Quick Reference Card

These quick reference cards are from *http://captnmike.com/2009/10/01/piloting-and-navigators-quick-reference/*

## Navigators Quick Reference Card

UNCORRECTING (−) E (+) W

TRUE
VARIATION
MAGNETIC
DEVIATION
COMPASS

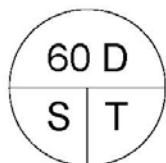CORRECTING (+) E (−) W

025 or 025T – TRUE

025M – MAGNETIC

025C – COMPASS

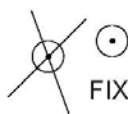TIME = 4 DIGITS (24HR)

COURSE = 3 DIGITS ( 000 (common) or 000.0 )

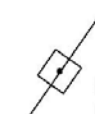S 10 or S 10.5 = SPEED ( 0.1 KTS MOST APPS)

RELATIVE BEARING + SHIPS HEADING = ACTUAL

$$\frac{C\ 090T}{S\ 10.5}$$

60 D
S | T

Distance
Speed
Time (Min)

FIX

DR

ESTIMATED
POSITION

Speed (S): S = ( 60 x D ) / T
Speed in Knots or Nautical Miles per Hour

Time (T): T = ( 60 x D ) / S
Time is always in minutes

Distance (D): D = ( S x T ) / 60
Distance is always nautical miles (nm)

1 nm = 1 Minute of Latitude = 6000 ft = 2000 yards (Many Calculations)
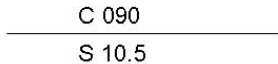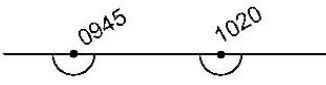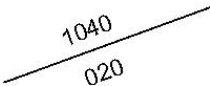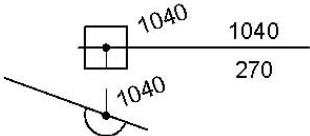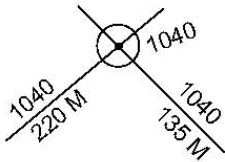60 nm = 1 Degree of Latitude
1 nm = 1852 meters = 6076 ft (International Treaties)
1 nm = 6100 ft (some calculations)
1 meter / second = 1.94 knots

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# Navigators Quick Reference Card

| ITEM | DIAGRAM | DESCRIPTION |
|---|---|---|
| DR Plot | C 090 <br> ——————— <br> S 10.5 | Course (090 True) written above line, Speed (10.5 Knots) written below line |
| DR Position | 0945      1020 | Time (24 Hour) Written at angle to semicircle denoting DR position |
| LOP | 1040 <br> 020 | Lightly draw line with Time (24 Hour) above LOP and True bearing beneath |
| Estimated Position | 1040    1040 <br> 270 <br> 1040 | Square located where dashed perpendicular line from DR position touches LOP |
| Visual Fix | 1040 <br> 1040 220 M    1040 135 M | Circle where two or more LOP's cross. Time written parallel to LOP lines |
| Electronic Fix | • 0950  RADAR <br> GPS  LORAN | Time and method (if relevant) |
| Running Fix | • 0950  R FIX | Circle containing the intersection of a given LOP and another LOP advanced (or retired) in time with RFIX and the time taken |
| Known Position | △ 1020 | Triangle with Time written alongside |

Summary of Common Navigation Drafting Symbols and Their Usage
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**APPENDIX E:**
**Sample Problem Chart[46]**
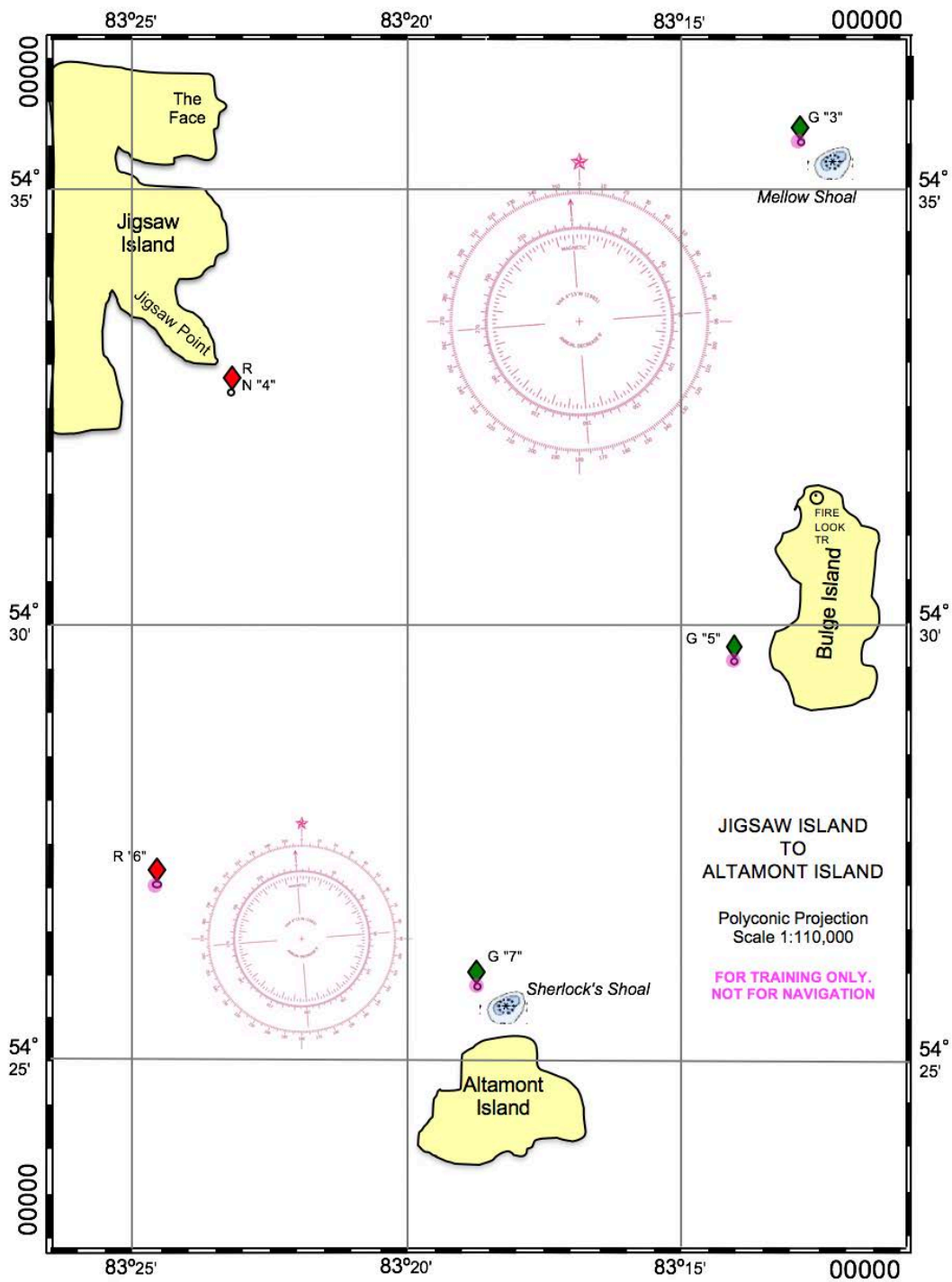


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# Acronyms and Abbreviations

| | |
|---|---|
| AIS | Automatic Identification System |
| ATON | Aid to navigation |
| DMS | Degree, minute, and second notation |
| GPS | Global Positioning System |
| kn | Knots (nautical miles per hour) |
| LMN | Local Notice to Mariners |
| LOP | Line of position |
| NGA | National Geospatial-Intelligence Agency |
| nm | Nautical miles |
| NOAA | National Oceanic and Atmospheric Agency |
| NTM | Notice to Mariners |
| RPM | Revolutions per minute |
| USCG | U.S. Coast Guard |

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# Acknowledgements

# About the Author

Gary C. Kessler was certified as a SCUBA diver as a teenager in southern California in 1967. He was later certified as an Open Water Diver, Advanced Open Water Diver, and Rescue Diver by the Professional Association of Dive Instructors (PADI) as part of the Colchester (Vermont) Rescue Dive Team in 1991. In 2009, Gary became a PADI Divemaster and Open Water SCUBA Instructor, becoming a Master SCUBA Diver Trainer in 2011.

Living on Lake Champlain (the sixth largest fresh water lake in the U.S.) and wanting to dive whenever he wanted, Gary bought his first boat in 1994 and received his initial USCG inland waters captain's license in 2012; he currently holds a 50 GT Master license with a Tow Assist endorsement. Gary is also a member of the USCG Auxiliary, 7th District, Flotilla 44 (Daytona Beach), where he holds coxswain and ATON Verifier qualifications.

Gary currently lives in Ormond Beach, Florida, and is on the ICW (Halifax River and Indian River Lagoon) and waters near Ponce Inlet at least a couple of times a week. He also drives an eco-tour boat for the Marine Discovery Center (New Smyrna Beach). In his other life, Gary is a principal consultant at Fathom5, a retired professor of cybersecurity from Embry-Riddle Aeronautical University in Daytona Beach, and a Certified Information Systems Security Professional (CISSP). He is a cybersecurity and digital forensics consultant, educator, and practitioner, with a particular interest in maritime cybersecurity, and is the co-author of *Maritime Cybersecurity: A Guide for Leaders and Managers*. Gary is active in cybersecurity readiness efforts at the national level of the USCG Auxiliary, and is a former and recurring visiting faculty member at the USCG Academy in New London, CT. Gary holds a B.A. in Mathematics, M.S. in Computer Science, and Ph.D. in Computing Technology in Education.