
Color Management

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Introduction

The goal of color management is to make colors look the same regardless of the hardware or platform used to capture, view or print them. Without color management, colors can shift significantly when images are scanned, viewed, or printed.

While color management has been part of Microsoft Windows since Windows 95, it was greatly improved with the introduction of ICM 2.0 in Windows 98, Windows ME and Windows 2000. And, many scanners and printers now come with color profiles and ICM-aware drivers. This makes it easier than ever to make your electronic color darkroom handle color in a consistent and controlled fashion from end to end.

With Version 3.0, Picture Window Pro fully supports color management. This includes using color profiles when loading and saving images, scanning, editing, printing and proofing.

While color management can be a little intimidating at first, most of the work is in setting up the system. Once you configure it correctly, you can largely forget about color management and still be confident of achieving consistent results that make good use of the color capabilities of your hardware.

ICC Color Profiles

Image color management (ICM) in Microsoft Windows is based on *ICC color profiles*—files which contain data representing the color characteristics of a particular device such as a scanner, monitor or printer. These profiles are created by carefully measuring the colors of standard color test targets with a colorimeter or spectrophotometer and processing this data using specialized profile creation software. Fortunately, a cross-platform standard for encoding color profiles has been defined by the ICC (International Color Consortium) and adopted industry wide. For more information on color profiles, see the ICC web site at <http://www.color.org>.

Custom Profiles

In most cases, the scanner and printer color profiles you need are supplied by the manufacturer so you don't need specialized equipment and software to create custom profiles to get good results. On the other hand, there are good reasons to create your own custom profiles:

- The characteristics of a given color device can change over time because of variations between different batches of printer paper and inks, aging of scanner light bulbs and monitor phosphors etc., and these variations can cause inconsistent color.
- You may wish to experiment with papers or inks that are not currently supported by a printer vendor or use a scanner or monitor that does not come with a profile. Finally, the only definitive way to calibrate a monitor to match specific standards is with specialized hardware and software.
- If you want to use a working color space other than sRGB, you will need to create custom scanner and printer profiles. The issue of working color space is addressed in more detail later in this document.

Profile Types

There are a number of different types of profiles, but the three common types are scanner profiles, monitor profiles and printer profiles. As you might expect, scanner and printer profiles are used to characterize image input and output devices. Monitor profiles serve a dual function—they can be used to define the characteristics of a specific monitor or they can be used to define the properties of an *RGB color space*. A color space profile is a precise definition of the meanings of the numbers that make up red, green and blue layers of a color image. Associating a

color space profile with an RGB image removes any possible ambiguity about the colors represented in the image.

Where Profiles are Located

By convention, color profiles are files with the extension “.icm”. Under Windows 98 and Windows ME, profiles are stored in your computer’s Windows\System\Color folder; under Windows 2000, they are stored in WinNT\System32\Spool\Drivers\Color.

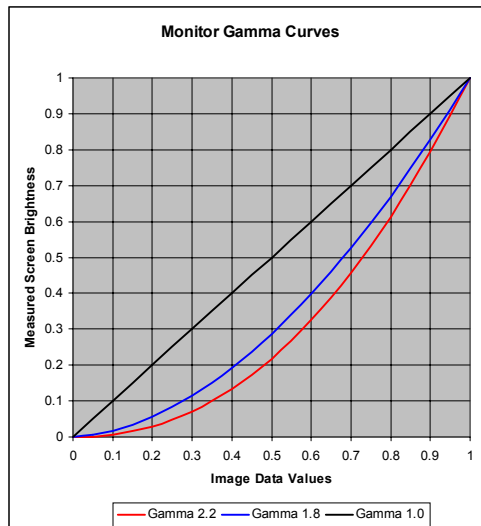
Color Gamuts, Gamma, White Point and Color Spaces

Color Gamuts

Each device has its own *color gamut* which is simply the range of colors it can capture, display, or print. An *RGB color space* is the set of all colors you can generate using any possible combination of red, green and blue values in an image.

Gamma Curves

A set of *gamma* curves represent how the image data in an RGB image file translate into measured screen brightness for each color. Commonly, an ideal gamma curve is represented as an exponential relationship which approximates the response of the human visual system. In this case, the gamma curve is described by a single number which is the exponent value. In Microsoft Windows, a standard gamma of 2.2 is the most commonly used value, and this is also the standard used for the web, video, most monitors, and Photo CD. The prepress standard is gamma 1.8 which is approximates the characteristics of a printing press.



White Point

When you see light reflected from or transmitted through something, you are viewing *object color*. When you look at a light source such as a lamp or a neon sign, you are viewing *self-luminous color*. To understand the difference, suppose you display a large yellow square on a computer monitor—you would perceive the image as yellow. Next, suppose you illuminate a sheet of white paper with the same yellow light. Even though the same yellow light is reaching your eyes, you would perceive the paper as white since you intuitively understand that the yellow color of the paper is due to the light, and you compensate automatically. If you view the yellow light reflecting from the paper through a small opening, you would again perceive the color as yellow since this removes the visual cues that let you infer the true color of the paper. In most cases, the human visual system is very good at figuring out the colors of objects regardless of the illumination, but in doing so it alters the perceived color of the image it receives.

The *white point* of a monitor is the color you get when you display white on the screen (white is defined as the color you get when you set R, G and B to their maximum values). Due to deficiencies in the red phosphor, an uncorrected computer monitor typically has a very blue white point with a color temperature of 8000-9500°K. Daylight is typically in the range from 5000°K to 6500°K, and most incandescent and halogen lamps are between 2600°K and 4200°K (see Monitor Calibration below for a lot more information on color temperature). When you observe a scene, your eyes and brain quickly analyze and cancel out the effects of different white points so the blue cast of the monitor is hardly noticeable until you compare it to a sheet of white paper illuminated by incandescent or halogen light. When viewing prints, the light reaching your eye comes from the light source illuminating the print and is reflected off the surface of the print and therefore the color you see depends on the color of the light. Different light sources (such as direct sunlight, indirect sunlight, incandescent light bulbs, fluorescent light bulbs and halogen light bulbs) all have different spectral characteristics. For the purposes of color management, these real world light sources are represented by idealized *standard illuminants*.

To get a close match between colors on your monitor and prints, the white point of your monitor must be close to the color of the light illuminating the print. The white of a print will always be the color of the viewing light reflected off of the paper the image is printed on. If the monitor white is different there will be an apparent color shift between the monitor and the print. If the monitor color temperature is higher than the color temperature of the viewing light, an image viewed on the monitor

will have a blue/cyan color cast compared to a print made from the same image. If the monitor color temperature is lower, the image on the screen will look more red/orange than the print.

The most commonly used white points are *D65* and *D50*. *D65* has a color temperature of around 6500°K and is the standard illuminant used in the sRGB color space (the Windows default color space), as it looks somewhat brighter on a monitor. A *D50* white point has a color temperature of around 5000°K and is the prepress standard. While images displayed on a *D50* monitor are a less brilliant and more yellow than with *D65*, in you may achieve better color matching between your CRT and prints using a *D50* white point for your monitor, depending on the light you are using to illuminate the prints.

When comparing prints to images on your monitor, it is important to control the color of the light used to illuminate the print and to avoid casting stray light onto the monitor screen. One of the best ways to accomplish this is to use a commercial viewing booth which is simply a box open in the front and illuminated by internal daylight-corrected fluorescent bulbs. Unfortunately, commercial viewing booths are expensive and tend to take up a lot of desk space. A less inexpensive alternative to a viewing booth is the *Ott-Light*. Available as a desk or floor lamp, it includes a daylight-corrected bulb with a color temperature of around 5500°K (for more information, see the section on commercial color management solutions at the end of this document). Just make sure you place the light behind your monitor and dim the room lights so that stray light does not hit the face of the monitor.

RGB Color Spaces

The set of colors that can be represented by combinations of a specific set of primaries, along with a white point and a set of gamma curves defines a *monitor color space*, also called an *RGB color space*.

For monitors and other devices that work by simply adding together primary colors, the color gamut can be represented by a triangle with its red, green and blue primary colors each at a vertex. These primary colors are in turn determined by the physical properties of the phosphors embedded in the face of the monitor. Since most CRTs use the same phosphors there is relatively little color variation from one monitor to another.

The Windows default color space is call *sRGB*. This color space has a gamma of 2.2 (with some very minor adjustments to very dark colors), a *D65* white point and

color primaries that correspond closely to standard CRT phosphors. While sRGB is a good choice for creating images for use on the web, video production and getting good matches between a monitor and a printer, its color gamut omits some of the most intense colors that color film, scanners, and digital cameras can capture and printers can reproduce. Conversely, there are colors a monitor can display that cannot be accurately reproduced on most printers.

Device-Independent Color

Human vision does not independently register each color frequency in the spectrum, but is based instead on just three primary colors—red, green and blue. Each of these primary colors of the visual system is composed of a weighted average of various wavelengths of light according to well-known curves called *color-matching functions*. Thus, any colored light can be broken down into three numbers called *tristimulus values* (X, Y and Z) corresponding to the degree to which the light matches the spectral sensitivity curve for each of the visual primaries. Consequently, any color the human eye can see has a corresponding unique set of XYZ tristimulus values. This XYZ color space forms the basis for the ICM 2.0 color management engine—all transformations it performs from one color space to another are done via its *profile connection space* (PCS): either CIE XYZ or CIE Lab which is mathematically equivalent. Such color spaces are called *device-independent* as they specify colors as they are perceived by the human eye, not as captured, displayed or printed by a specific device. While the CIE color model is a simplified version of the real world in which various other factors affect the way we perceive colors, it works surprisingly well for a broad range of applications.

Without knowing what color space they are in, the RGB values in an image file have no real meaning. But, given an associated color space, it becomes possible to translate the RGB numbers in the image file to their corresponding device-independent XYZ tristimulus values. Associating a color profile with the image at each stage—scanning, editing and printing, makes consistent color management possible from one end of the electronic darkroom to the other.

Rendering Intents

Since every device that handles color has its own unique characteristics, even the best color management system cannot make an image look identical on each one. The Windows ICM 2.0 color management engine supports four different methods for resolving conflicts between color spaces with different gamuts. The method it uses is determined by the *rendering intent* you specify. For purposes of illustration, let's call the original color space A and the color space we are converting to B. The four ICM rendering intents are:

Maintain Full Gamut

This is also called *picture intent* or *perceptual intent* and is the default you should normally select when working with photographic images. When you use this rendering intent, the full gamut of color profile A is stretched or compressed to match the full gamut of color profile B. This guarantees that all colors in both profiles will be available, but some colors that could be matched perfectly because they lie within both color gamuts may be altered slightly.

Preserve Saturation

This is also called *graphic intent* or *saturation intent* and is designed for working with charts and business graphics. When converting colors, this intent preserves the saturation of colors in profile an image at the expense of changing their hue and brightness in some cases.

Preserve Identical Colors and White Point

This is also called *proof intent* or *relative colorimetric intent* and preserves colors that are within both color gamuts and preserves the white point of the image. Colors in the input image that lie outside the color gamut of the output image are changed to the nearest matching color. This gives the most accurate possible match for colors within both color profiles but may result in loss of color detail in areas outside the gamut of the input or output images.

Preserve Identical Colors

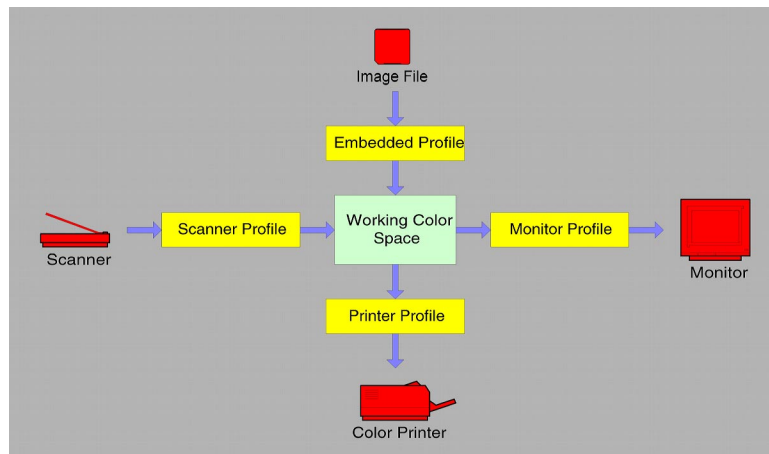
This is also called *match intent* or *absolute colorimetric intent* and preserves colors that are within both color gamuts and does not preserve the white point of the image. Otherwise it is identical to proof intent (see above).

Working Color Space

While not strictly necessary, it is strongly recommended that you convert images on input to a *working color space*. This is the RGB color space to which you convert images when you load them or scan them, in which you edit your images, and from which images are converted when you print them. The working color space is selected from the *File/Color Management* dialog box. There are three good reasons for using a Working Color Space:

- If all of your images are not in the same color space, this can lead to unexpected color shifts when combining images as the meaning of the RGB image data changes depending on the color space. In fact, Picture Window issues a warning if you attempt to combine images with different color profiles.
- Converting images to the working color space irons out all the nonlinearities in the original device's color space yielding standard RGB data. This in turn makes image editing operations more accurate.
- There are performance advantages to working in a standard RGB color space since it is easier to translate to the monitor and printer color spaces.

The following diagram illustrates how Picture Window translates image data from one color space to another via the working color space:.



Choosing a Working Color Space

The default Windows working color space is *sRGB*—a color space designed around the properties of a typical color monitor. This is a good choice when creating images for use on the web, for multimedia presentations, for video, for exchanging files with other computers or programs that do not support color management, or when getting the most accurate possible match between images displayed on your monitor and output to your printer is your primary concern.

The biggest problem with *sRGB* is that it excludes some colors (primarily dark, intensely saturated colors) that can be captured on film and/or printed on printers. This causes the working color space to become a potential bottleneck through which the most intense and dramatic colors can have difficulty passing without being altered.

Two alternative color spaces called *Chrome 2000 D50* and *Chrome 2000 D65* are provided with Picture Window. These are gamma 2.2, D50 and D65 color spaces with a considerably wider color gamut than *sRGB*. In fact, just about any color that can be captured on color transparency film or printed on a printer lies within the Chrome 2000 color gamut. Working in these color spaces avoids having to compress the colors in an image that fall outside the *sRGB* gamut to fit its narrower range of colors. Similarly, the extended color information in a Chrome 2000 image lets you print without having to extrapolate the range of colors in the image to fill the printer gamut.

There are two possible reasons not to select Chrome 2000 as your working color space, however. First, if all the colors in your image are confined to the smaller *sRGB* color gamut, you are simply wasting color space by using Chrome 2000 as all the colors will be crowded into the central part of the color gamut. This in turn can lead to minor loss of subtle color information. Second, Chrome 2000's color gamut is so much broader than the typical monitor gamut that noticeable color differences can arise between the colors specified in the image and the colors you see on your screen. This is caused by the distortion of the color space required to shoe-horn all the Chrome 2000 colors into the more limited monitor color space and can lead to some small, unexpected color shifts.

Chrome 2000 is supplied in D50 and D65 versions because the D65 version usually works a little better with properly balanced film images. For some reason, Photoshop 5.5 does not let you load Chrome 2000 D65 for use as a working color space, although it does accept the D50 version and it does allow Chrome 2000 D65 as an embedded profile. Thus, if you need to use Picture Window and Photoshop 5.5 side

by side with the same working color space, and if you want to use Chrome 2000, then you must use Chrome 2000 D50.

If you are willing to give up some color gamut (see the chart at the end of this section) in exchange for virtually eliminating all color shifts, the you may wish to use either SMPTE-240M or Bruce RGB as your working color space.

The following is a list of the color profiles included with Picture Window that you can use for working color spaces:

sRGB IEC61966-2.1

This is the Windows default color space, based on the colors that can be displayed on a video monitor. It is very similar to both PAL-SECAM and SMPTE-C (see below). This is the best color space to use when creating images for display on PC monitors or for the web, or for exchange with other computers or applications that do not recognize color space information in image files.

Chrome 2000 D65 & Chrome 2000 D50

The *Chrome 2000* color spaces have a wide color gamut designed to encompass all the colors that can be recorded on color transparency films. This is an alternate color space for scanning, printing, and archiving images that originate on film as it includes nearly all the colors most films can capture, most scanners can detect, and most printers can print. You may see slight color shifts when you use this color space. The D65 version is recommended for most purposes but cannot be used as a working color space in Photoshop 5.5.

SMPTE-240M [a.k.a. Adobe RGB (1998)] & Bruce RGB

These are good all-around choices for a slightly wider gamut color space than sRGB. As of Photoshop 5.5, Adobe renamed their version of the *SMPTE-240M* color profile *Adobe RGB (1998)*. *Bruce RGB* is a similar color space with a somewhat reduced color gamut. Either of these color spaces has less of a problem with color shifts than *Chrome 2000*.

SMPTE-C, PAL-SECAM & NTSC (1953)

SMPTE-C is a color space based on the USA video standard while *PAL-SECAM* is based on the European standard. These color spaces are good choices for creating images that will be transferred to video. *NTSC (1953)* is another video-oriented color space, but it is based on obsolete monitor phosphors and should not be used under normal circumstances.

Wide Gamut RGB

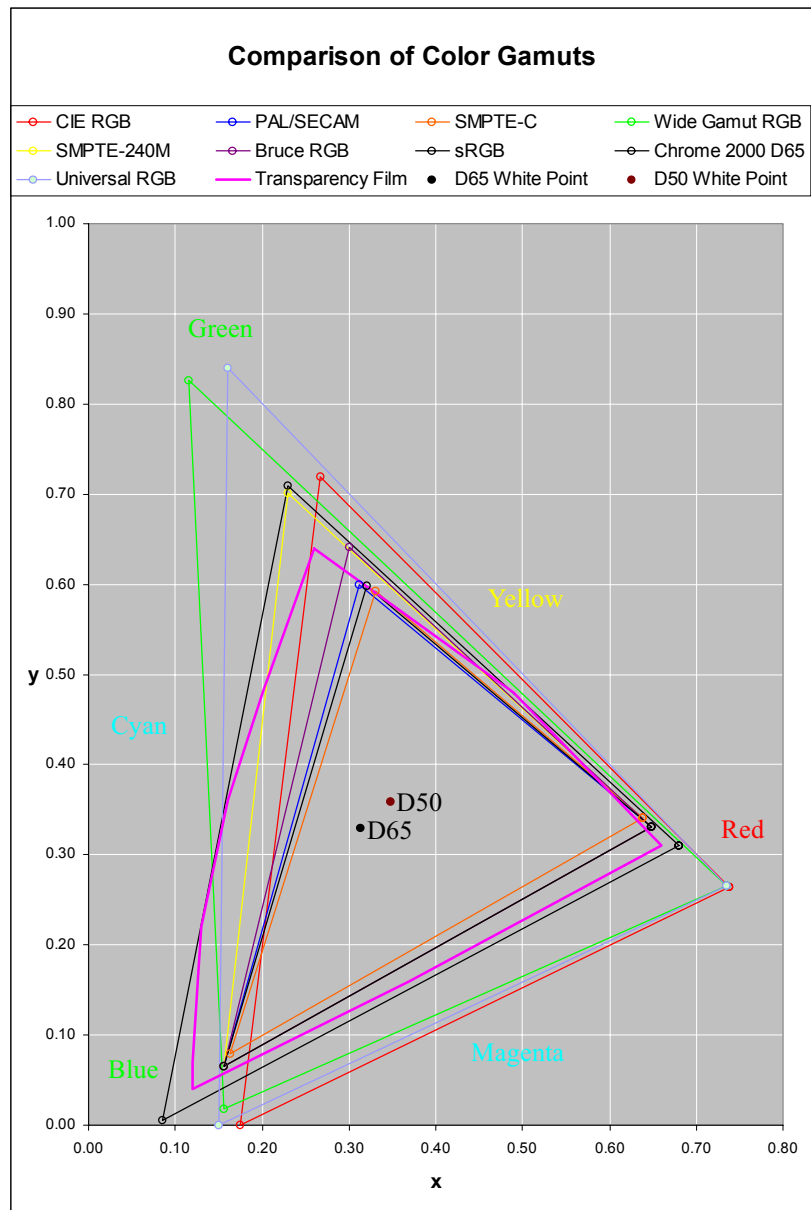
This is a very wide gamut color space based on spectrally pure primary colors. It is not recommended for normal image editing as much of the gamut is taken up by colors nearly impossible to reproduce on any device.

Universal RGB

This is another very wide gamut color space defined so as to include most *surface colors*, i.e. the colors in real world scenes. This space includes many colors that cannot normally be captured on film or by scanners. This color space is based on the published primaries in the *Reference Output Medium Metric* (ROMM) and *Reference Input Medium Metric* (RIMM) color spaces developed by Kodak and accepted as an ISO standard.

CIE RGB

This is a profile based on the primary colors used in the *CIE Lab* color space. It is not recommended for use as a working color space.



Creating Custom Profiles

While it is becoming increasingly common for scanners, monitors and printers to come with ICC color profiles you can use to create a color managed workflow, there are several reasons why you might want to create and use custom profiles.

- There is no profile available for your scanner, printer or monitor.
- You want to print images using a combination of inks and paper for which you have no profile.
- You want to use a working color space other than sRGB.
- You suspect your scanner or printer is not conforming accurately to the supplied profile.
- You want to accurately calibrate your monitor.

How profiling works

Custom profiles are created by measuring the way your scanner, printer or monitor reproduces color. The method for creating profiles depends of the type of device being profiles. Picture Window does not come with software or hardware to create custom profiles, but there are a number of other companies that provide color management solutions. A partial list of these companies and their products can be found at the end of this document.

Profiling a Scanner

For scanners and other input devices, profiling is done by scanning a test target containing a number of color patches of known properties. The standard test target is typically an IT8 transparency (for film scanners) or print (for flatbed scanners) whose characteristics are described in a companion reference file.

Profiling digital cameras can be problematical as there is often circuitry in the camera to adjust the exposure and white point of the image depending on the subject matter. Useful profiles can only be created if the characteristics of the device are kept strictly constant.

Profiling a Printer

For printers, profiling is done by printing a test target containing a number of color patches and then measuring the color of each patch either using a colorimeter or spectrophotometer or by scanning it using a calibrated flatbed scanner. The former

method is the most accurate but requires purchasing a color measuring instrument. The scanner method is less accurate but can be a lot less expensive.

It is critically important for printer profiling that all adjustments in the printer driver be turned off when printing the test target and when printing subsequent images using the custom profile. A printer profile is only valid assuming that the same inks, paper and driver settings are used at all times.

Profiling a Monitor

Profiling a monitor involves correctly setting the brightness, contrast and color controls on the monitor and then measuring the colors of a series of color patches displayed on the screen using a colorimeter or spectrophotometer. In most cases this requires a different instrument than is used to measure printed test targets although there are a few devices that can be used for both purposes. While there are alternative methods for monitor calibration and profiling which do not require special hardware such as the monitor overlay which ships with Picture Window, using a monitor measuring instrument is by far the most accurate and repeatable method.

Loading and Saving Images

Most image file formats represent colors by three values: their red, green and blue components, usually referred to as *RGB color*. Raw RGB numbers from a scanner or sent to a printer do not have well defined meanings as they depend on the characteristics of the input or output device. But, when combined with a color profile, RGB data takes on a precise meaning independent of the characteristics of any device, platform or operating system.

The specifications for a number of the standard image file formats including TIFF, BMP, PNG, JPEG, GIF, FlashPix and EPS have been extended to optionally permit a color profile to be embedded in the same file as the image data. If present, this embedded color profile provides the information necessary to interpret the RGB values in the file in a device-independent manner. Some of the older formats such as PCX and Targa do not support embedded profiles and should not be used in a color managed environment.

NOTE: Picture Window currently supports loading and saving embedded color profiles in TIFF, JPEG and BMP files only. Picture Window support for embedded profiles in PNG, GIF, FlashPix and EPS files will be added when improved support for these file formats becomes available from the supplier of the DLLs we use to load and save these files.

Photo CD files are written using a standard color space called *Photo YCC* which is similar to sRGB. Picture Window automatically converts from Photo YCC to the current working color space when it reads images from a Photo CD.

Over the years, the BMP file format has been extended several times. Only the latest Version 5.0 specification allows for embedded color profiles. Not all programs that read and write BMP files have been modified to read Version 5.0 BMP files. Some programs may have difficulty reading these files or they may simply ignore the embedded profile. For example, use of Version 5 BMP files as wallpaper under Windows is not supported. While Photoshop 5.5 reads BMP V5 files without giving an error, it strips out any embedded profile, and when saving BMP files, it writes them in the old BMP format that does not include a profile. When you save BMP files from Picture Window, you are given the option of saving them in the old format for compatibility with older programs or the new format to preserve the color information.

Programs that do not recognize the color information embedded in TIFF or JPEG files will normally just ignore it.

If you use any color space other than sRGB, the program you are exchanging files with must support color management or the images will undergo a color shift when you save them using Picture Window and then load them with the other program. For this reason, sRGB is the safest color space to use if you will be exchanging files with other programs unless you know they support color profiles (e.g. Photoshop 5.x or later).

When loading an image that has no associated profile, an *assumed color profile* is assigned to the image. You can specify the assumed color profile in the *File/Color Management* dialog box. The default assumed color profile is *sRGB*.

After loading an image, its color profile is compared to the working color space. If they are different, depending on a *File/Color Management* setting, Picture Window will ask you if you want to convert the image to the working color space or leave it in its original color space, convert it without asking, or leave it in its original color space without asking.

The Windows Clipboard

The Windows clipboard does *not* support embedded color profiles. This means you should only use the clipboard to transfer color images in the sRGB color space. Transferring images via the clipboard in any other color space will result in color shifts. Under Windows 95/98/ME, the Windows Clipboard is also limited to a maximum image size of 16MB.

To export images to programs that support color management, save them as TIFF files and open them in the other application.

To export images to other programs that do not support color management, first use Picture Window's *Change Color Profile* transformation to change the image and profile to sRGB and then either use the clipboard or save the image in a file and open it in the other application.

Displaying Images on Your Monitor

Sooner or later you will probably get around to viewing images on your monitor.

Monitor Profiles

Ideally, you should have a color profile for your specific make and model of monitor. While most CRTs use the same P22 phosphors and consequently have very similar characteristics, LCD (liquid crystal) screens found on laptops and thin-panel desktop displays have different primary colors and can be problematical due to color and brightness variations with viewing angle. Using LCDs for critical color work is not recommended.

You can select a profile for your monitor from the *File/Color Management* command. You can optionally select *proofing* in this dialog box and this will let you preview how image will look when using a particular printer and printer profile (see the section on Proofing below for more details). To disable the use of a monitor profile, select *None*.

When displaying images, Picture Window converts the RGB data from the color space specified by the color profile associated with the image to the color space specified by the current monitor profile (via the proofing profile, if any).

Monitor Calibration

To obtain consistent results, accurate monitor calibration is very important. Monitor calibration ensures that the white point of your monitor is set correctly, that neutral grays display neutral, and the gamma of the monitor are set to the correct curves, resulting in good overall tonal balance. The gamma curve is simply the measured brightness of the screen as a function of the levels in an image from 0 to 255.

Step 1 -- Clear all monitor settings

Before you start the monitor calibration process make sure all your display adapter settings are reset to their default values. Some video card manufacturers like Matrox install a control panel with their display driver that lets you adjust the white point and gamma of your display. If the display adapter has gamma controls, setting them can be confusing. For example, sometimes the default value is 1.0 in which case the gamma they are referring to is not

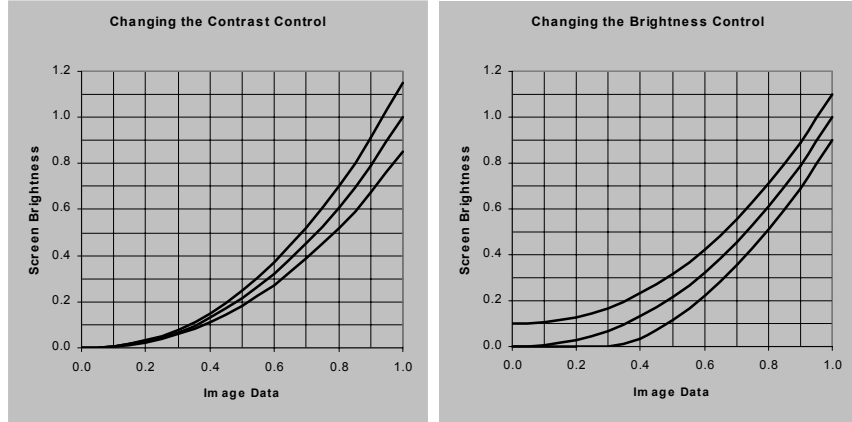
the actual monitor gamma but a correction factor by which the native monitor gamma (normally 2.2 or slightly higher) is multiplied; for Picture Window, the monitor gamma must be set to 2.2.

Step 2 -- Warm up and ensure proper viewing conditions

Make sure your monitor is fully warmed up, and there is as little room light as possible. Viewing a monitor in a brightly lit area or where light is hitting the screen directly or reflecting off the screen into your eyes makes accurate calibration impossible.

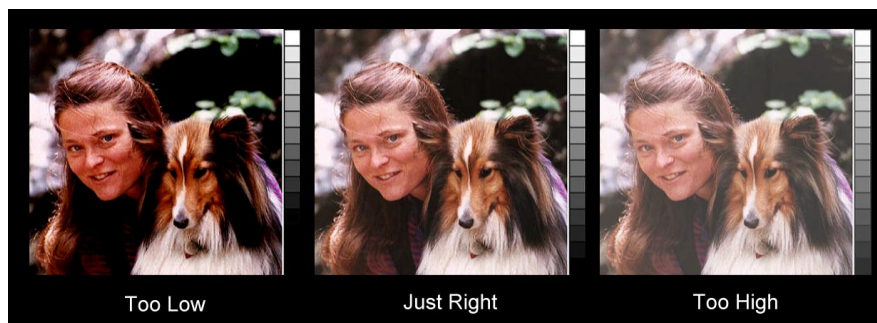
Step 3 -- Set your monitor's brightness and contrast controls

Setting the brightness and contrast controls on your monitor correctly is *very* important. The contrast control acts as a multiplier making the image lighter or darker while preserving the relative tonalities of its shadows, midtones and highlights (see below). Typically the best results are obtained with the contrast control turned all the way up as this gives the greatest contrast between black and white. If the resulting image is uncomfortably bright, you can back off the contrast control to suit your personal preference.



The brightness control raises or lowers the brightness level across the entire tonal range. Referring to the diagram above, the ideal brightness setting is the middle curve. Too high a setting makes the image washed out by turning black into gray; too low a setting causes a loss of shadow detail by turning an entire range of dark grays to solid black.

As an aid in setting the brightness control Picture Window's File/Monitor Calibration command displays a sample image (see below) and a series of graduated gray patches. Too low a brightness setting will make the image muddy and the darkest two gray patches will be hard to distinguish. Too high a setting will make the image appear washed out...



Step 4 -- Calibration

Some video cards have drivers that incorporate *color lookup tables*, sometimes called *LUTs*. Drivers with lookup tables are better suited to monitor calibration. Once you load the correct data into the lookup tables, everything you display subsequently in any program you run on your computer will be color corrected. In the absence of lookup tables, each program must handle calibration independently. You can tell if your video card has lookup tables from the *Help/About Picture Window Pro* dialog box.

To achieve the most accurate possible monitor calibration, you need to use a sensor that attaches to your screen by suction cups. You then use a calibration program to display a series of color patches on the screen for the sensor to measure. From these individual color measurements, the calibration software automatically generates a set of lookup tables used to conform your monitor to specific standard conditions. For this type of calibration to work, your display adapter must be capable of working with lookup tables, the lookup tables must be reloaded with the correct values each time your computer starts up, and you must leave your monitor's brightness, contrast and color controls in the same positions they were in at the time of the calibration.

If your monitor has individual gain settings for red, green and blue, you can use them to adjust your monitor's white point. Some monitor calibration sys-

tems let you use these color controls to set the white point of your monitor with a sensor attached to the screen so you can achieve exactly the color temperature you want without using lookup tables. This is the ideal method as using lookup tables to adjust the white point makes slightly less efficient use of the digital image data.

If you don't want to purchase monitor calibration hardware, you can use Picture Window's monitor calibration which works with a special film overlay. There are also software-only monitor calibration solutions available from other vendors. These other programs, while not as accurate as Picture Window for monitor calibration, can also be used to create custom scanner and printer profiles if you have a flatbed scanner. First you calibrate your scanner using a standard IT8 test target and then you print out a printer test target and scan it to calibrate your printer.

The target monitor gamma

The target monitor gamma value you should calibrate to is 2.2 as this corresponds closely to the native gamma of the monitor and display adapter and also is a good representation of the response curve of the human eye. The prepress industry standardizes on a gamma value of 1.8 which more closely approximates the characteristics of a printing press. Picture Window is designed to work only with a monitor gamma of 2.2.

The target white point

The choice of a target white point is a little more complicated. Because the eye adapts easily to different colors of light, you may not even notice if the white point your monitor is way off until you compare on-screen images to prints made from those images. Most uncorrected monitors have a distinctly blue cast as the red phosphor is weaker than the green and blue ones, but this color cast is not really noticeable until you hold up a piece of white paper next to the monitor.

If you want to get as accurate as possible a match between your monitor and your printer, you need to match the white point of the monitor to the color temperature of the light in which you will be viewing the prints. Typically choosing a D50 white point will give the best match for indoor lighting while D65 works best for outdoor illumination. Color temperature is a scale for measuring the color of light based on black body radiation and is measured in degrees Kelvin (°K). Lower color temperatures are more yellow/

orange and higher temperatures more blue. The following list gives a sampling of approximate color temperatures for different light sources:

Match Flame	1,700°K
Candle	1,800-1,950°K
40-Watt Bulb	2,650°K
100-Watt Bulb	2,850°K
500-Watt Bulb	2,950°K
Photo floods	3,200-3,400°K
Quartz Halogen Bulbs	3,250-4,200°K
Moonlight	4,000°K
Electronic Flash	5,500°K
Sunlight at Sunset	2,000°K
Sunlight 1 Hour Before Sunset	3,500°K
Late Afternoon Sunlight	4,300°K
Summer Noon Sunlight	5,400°K
Overcast Sky	6,000°K
Average Summer Daylight	6,500°K
Light Summer Shade	7,100°K
Full Summer Shade	8,000°K
Summer Skylight	8,000 - 30,000°K

The commonly used monitor calibration white points are:

D50 (for all practical purposes identical to 5000°K)

This is the graphic arts and prepress standard for matching standard viewing booths and light boxes. Compared to D65 (see below) a D50 white is noticeably yellow—using this value can make on-screen images look less brilliant, but incandescent and halogen lighting is yellower still. This is the recommended white point to use if you want to get the most accurate match between your monitor and prints viewed using a commercial D50 light booth.

5500°K

This is an approximation of mixed sunlight and shade and is the color temperature to which electronic flash and daylight film are normally balanced.

D65 (for all practical purposes identical to 6500°K)

This is the standard value for daylight, assuming a mix of direct sunlight and indirect blue sky light. On-screen images displayed using this white point are brighter than at 5000°K, but are significantly more blue than most indoor lighting. If you use this or especially one of the even higher temperature white points you may have trouble getting images to match between your monitor and your printer.

7500°K

This is the standard value for north light or lighting from an overcast sky which is more blue than direct sunlight

9300°K

This is the typical white point of an uncorrected monitor. While much too blue to match normal lighting conditions, on-screen images are very brilliant.

The Relationship between Monitor Profiles and Monitor Calibration

The standard system for using monitor calibration and profiles defines their relationship as follows:

- *Monitor calibration* is used to make your monitor's characteristics conform to those of a specific standard. Since you cannot change the primary colors of the monitor phosphors by calibration, calibration is limited to adjusting the monitor's brightness, contrast and color controls and adjusting the gamma curves. A typical standard might be gamma 2.2 with a D50 white point.
- The *monitor profile* tells the color management system what standard the monitor is calibrated to and what are the colors (in device-independent color coordinates) of its red, green and blue primaries.

In this scheme, the profile does *not* contain the color lookup tables for the monitor. Monitor calibration and profiling programs normally generate both a set of calibration lookup tables and a companion monitor profile to be used with the calibrated monitor. The system only works correctly when both of these are in effect at the same time. A small program that loads your video card's color lookup tables is normally placed in your Windows *StartUp* folder so it can reload the lookup tables into your video card each time you power up your computer. If you use Photoshop you should be aware that it installs its *Adobe Gamma Loader* program in your *StartUp* folder as well and this can compete with other software attempting preload the lookup tables if it is not removed or disabled.

All this being said, it is in fact possible to incorporate calibration lookup tables into a monitor profile and do away with separate color lookup tables and the program that reloads them on startup. If your video card does not use lookup tables, this may in fact be your best option. Some color management programs such as Monaco EZColor (see below) support this mode of operation if no lookup tables are available. The primary drawback of combining calibration and profiling is that only ICC profile-aware applications derive any benefit from the monitor calibration. The advantages are that it is easier to switch between different monitor settings such as D50 and D65 white points, and it is impossible to accidentally use one set of monitor calibration lookup tables with an unrelated monitor profile. Alternatively, if your video card does not have color lookup tables, you can use Picture Window's monitor calibration which simulates hardware lookup tables if they are not available.

Proofing

In addition to setting a monitor profile and rendering intent, Picture Window also supports a *proofing profile* and *proofing rendering intent* which you set from the *File/Color Management* dialog box. Proofing attempts to preview how an image will look when output to a specific printer for which you have a color profile. It works by first transforming your images to the printer color space and then converting a second time to the monitor color space. To disable proofing, set the proofing profile to *None*.

Proofing is intended to be used to preview how images will look on output devices such as a printing press which have a limited color gamut—at least as implemented in ICM 2.0, it does not seem to work particularly well with color inkjet or other color printers that can render certain colors that cannot be displayed on a monitor.

To summarize, there are many ways on-screen color can be altered, all of which need to be carefully controlled and coordinated to get consistent results:

- The settings of your monitor's brightness, contrast, and color controls.
- Any control panel settings that affect your video card's lookup tables.
- The calibration software that generates the color lookup table data and custom monitor profile.
- The program that loads the color lookup tables on power up.
- The monitor profile and rendering intent and proofing profile and rendering intent you select in Picture Window's File/Color Management settings.

Printing

Printer profiles are created by printing and then measuring a test pattern of colored patches. These measurements are then fed into profile creation software which turns them into an ICM file suitable for use as a printer profile.

For a printer profile to have any meaning whatsoever, the same exact paper, inks and driver settings in use when the original test pattern was printed must all be used again when subsequently printing images with that printer and profile. This means selecting the correct printer profile based on the medium you are printing on, the inks you are using, the resolution you are printing at, and the dithering method you are using, and then making sure that all the driver's color correction and tonal correction settings are set to make no corrections, and that any color management internal to the driver is disabled.

Unfortunately, no specific instructions for making these settings can be given here as the printer drivers and profiles are usually supplied by printer manufacturers or third parties and each one is different. Be very suspicious of any profile you obtain for your printer if it does not come with very specific information about what medium, inks and driver settings to use with it.

Generic printer profiles cannot take into account variations in production runs of papers or inks or other factors that can lead to inconsistent results. For complete control of the color of your prints, or if you need profiles for paper and ink combinations not provided by the printer manufacturer, you may want to consider purchasing the necessary equipment and software to create your own custom profiles. Some of the hardware solutions for custom profile creation also support precise monitor calibration as well (see below for more details).

Picture Window supports color management either within the printer driver or outside the driver.

To perform color management outside the driver, select a profile and rendering intent in the Print dialog box—this is the only way to use custom printer profiles. Since the Windows printer driver model only supports RGB images, CMYK or other non-RGB printer profiles cannot be used outside the printer driver.

To use the printer driver's color management, do not specify a profile in the Print dialog box and use the driver's color management settings (if any).

To summarize, there are many factors that can affect printer color, all of which need to be carefully controlled and coordinated to get consistent results:

- The condition of the printer.
- The type of paper and inks you are using.
- The software (and instrumentation, if any) that generates the printer profile.
- The printer driver settings.
- Picture Window's File/Color Management and printer profile settings.

Limitations of the Windows Driver Model

Inkjet and most other types of color printers create images by combining inks of four, six and sometimes even more different colors. Depending on their colors, the extra inks can be used to widen the color gamut of the printer, to improve its rendition of highlight detail, or both. Another option starting to appear are *quadtone inks*—a matched set of four neutral gray inks that run from light gray to black. By using the lighter inks to print lighter areas of the image, finer highlight detail can be reproduced and smoother tonal gradations can be obtained.

In an ideal world, a color management system would have individual control over the amounts of each individual ink so as to be able to make the best possible approximation to the original image as specified by a color profile. Indeed the ICC profile specification allows for working with printers that use four or more inks. Unfortunately, since Windows driver model only supports sending RGB data to a printer, all decisions about how to use the extra colors must be made in the printer driver. Since Windows printer drivers are difficult to write from scratch and impossible to modify without access to their proprietary source code, support for features like quadtone inks is mostly at the discretion of the printer manufacturers who have their own priorities, generally dictated by the consumer market.

The one exception to the RGB printer driver bottleneck is for Postscript printers. The Postscript printer language supports the CMYK color space and Postscript drivers are capable of bypassing the normal Windows data paths. This is of course only an option if you have a printer that incorporates a Postscript RIP. Unfortunately, since Picture Window does not support CMYK image data, even if you have a Postscript printer, you will have to use some other image editor if you want to experiment with quadtone inks at least until printer makers decide to support them in their drivers.

Scanning

When you scan from within Picture Window via your scanner's TWAIN driver, Picture Window assigns an *assumed scanner profile* to color image data transferred from the scanner. You can set the assumed scanner profile from the *File/Color Management* dialog box.

If you use stand-alone scanning software, you must save the scanned image as a TIFF or BMP file and then open it using Picture Window. If the scanning software associates a profile with the image file, this profile will be carried along with the image. If the scanning software does not associate a profile with the image file, the *assumed file profile* will be attached to the image when Picture Window opens it. You can set the assumed file profile from the *File/Color Management* dialog box.

Scanner drivers are gradually being upgraded to address color management. Ideally, you should set your scanner to convert its raw RGB image data to the *working color space* you have selected in Picture Window. Or, if you have a profile for your scanner, you can set it as the *assumed scanner profile* in the *File/Color Management* dialog box, and let Picture Window do the conversion later.

To summarize, there are many ways scanner color can be altered, all of which need to be carefully controlled and coordinated to get consistent results:

- The condition of the scanner.
- The software (and instrumentation, if any) that generates the printer profile.
- The scanner driver settings.
- Picture Window's File/Color Management settings.

The Color Space Associated with an Image

You can always tell what color space is associated with an image open in a window by selecting the window and invoking the *Window/Info* command. The name and type of the color space associated with the image are displayed at the bottom of the *Window/Info* dialog box.

You can change the color space of an image using the *Transformation/Color/Change Color Profile* command. This command lets you select a new color space for the image and can transform the image's RGB data from the original color space to the new color space. The resulting image is placed in a new window.

Workflow

This section explains how to set up and use color management in Picture Window to achieve consistent results.

Setup

Before you start manipulating any images, you need to configure color management appropriately.

Note: Picture Window's color management and monitor calibration commands will be grayed out unless you are using Windows 98, Windows ME or Windows 2000 and your display is set to 16-bit color or greater. If possible you should set your display to 24-bit or 32-bit color.

1) Monitor setup

Monitor setup consists of selecting the correct color profile for your monitor and ensuring that your monitor's characteristics conform to that profile. If no specific profile is available for your make and model of monitor you can use one of the generic monitor profiles as monitors vary only slightly. The easiest way to select a monitor profile is with the *File/Color Management* command. Once you have selected a profile, you need to establish good viewing conditions, set the contrast and brightness controls for your monitor correctly, and adjust its white point and gamma curve. This is ideally done using a monitor calibration program and a monitor colorimeter (see below), but you can use Picture Window's *File/Monitor Calibration* command.

Picture Window ignores the monitor profile settings in the Windows Display Control Panel (Under Settings/Advanced/Color Management). Conversely, the monitor profile you select in Picture Window's Color Management dialog box does not modify the Windows control panel settings and does not affect any other program. The monitor profile selection is completely independent from and has no effect on monitor calibration.

2) Choose a Working Color Space

If you are creating images for use on the web, for output to video, for interchange with programs or platforms that are not aware of color management, or to get the best possible match between your monitor and your printer, use the Windows

default color space: *sRGB IEC61966-2.1*. If you are using a digital camera or scanning images, editing them, and printing them yourself, use the Chrome 2000 color space as it has a color gamut wide enough to represent all or nearly all of the colors that any of the color devices can recognize.

3) Other Settings

The assumed color space should normally be set to *sRGB IEC61966-2.1*. In the absence of specific knowledge of the color space associated with a given file, this is probably the safest assumption. If you want to open a file with no embedded profile and you know what profile belongs with it, then select that profile as the assumed color profile before opening the file.

When opening a file whose color profile is different from the working color space, you have several options: you can have Picture Window ask you what you want to do or you can go ahead and convert to image to the working color space or leave it in its native color space. The safest is to ask, and this is the default setting. If you are using Chrome 2000 as your working color space, converting to that color space is likely to be relatively harmless as its color gamut is relatively wide. Converting to a narrow gamut color space such as *sRGB IEC61966-2.1* on the other hand can cause certain colors to be distorted. Finally, if you want to just edit a file and save it back out without changing its original color profile, this setting lets you work on it without altering the profile or transforming the image data to a different color space.

All rendering intents should normally be set to *Maintain Full Gamut* as this is the normal setting for photographic images. Other rendering intents should only be used for specialized applications such as printing business graphics or precise color matching where absolute accuracy is more important than overall appearance.

Loading and Saving Files

For now, Picture Window only recognizes and embeds profiles in TIFF, JPEG and BMP files. If you use any other file formats, you will have to keep track of the associated color profiles yourself. Avoid obsolete file formats such as PCX and Targa that do not support embedded color profiles. Support for embedded color profiles in GIF, PNG, and EPS files will be added as soon as possible, but this depends on cooperation from one of our suppliers.

Scanning

Unfortunately the TWAIN standard does not at this time support embedded ICC profiles. If you have a scanner that supports color management, this means you will have to either scan using a stand-alone software package that comes with the scanner and can save files in TIFF, JPEG or BMP format with embedded profiles or you can scan normally through the TWAIN driver, setting the Assumed Scanner Profile in the File/Color Management dialog box to the scanner profile for your scanner.

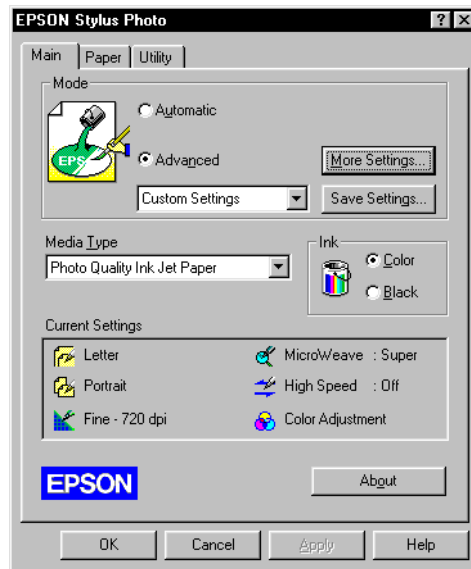
Printing

There are basically two ways to print using color management. You can either use color management in the printer driver (assuming the driver has support for color management), or you can apply a custom profile to the image before you print. If you choose the latter method, you will need a profile for your printer and you need to make sure that all the printer driver settings are exactly as they were when the profile was created.

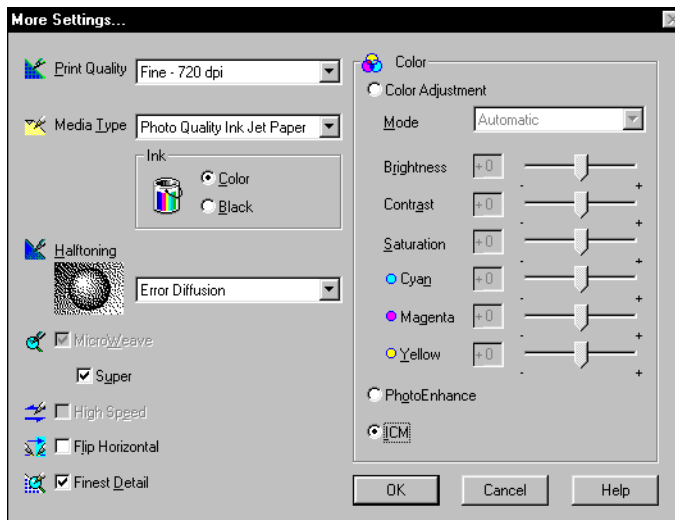
Using Epson printer drivers

The following information applies to Epson printer drivers for Windows 98 and Windows ME. The Epson printer drivers were rewritten for Windows 2000.

To print using color management within the Epson driver, you need to do a Printer Setup which displays the following dialog box (or something similar based on your printer):



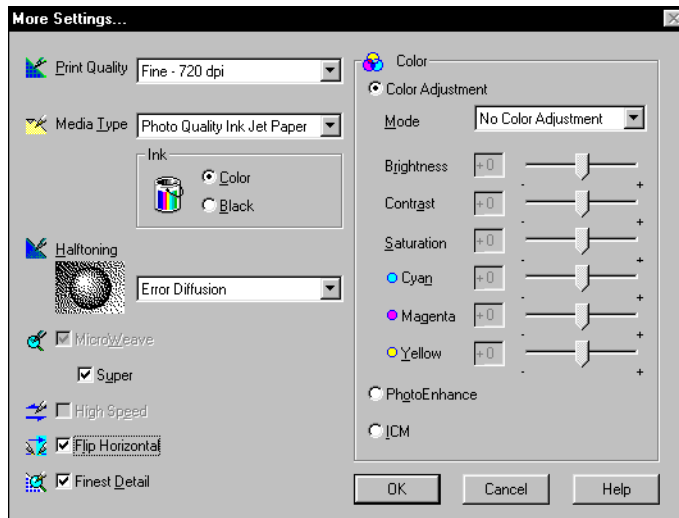
Click the *More Settings...* button to bring up the following dialog box:



Use this dialog box to select the Print Quality (use the best available for high quality photo printing) and Media Type. Then click the ICM radio button to select ICM color matching and leave the other color settings unchanged. This will cause the printer driver to attempt to match its output to the input image which it assumes is in the sRGB color space. When printing with these settings, leave the Custom Profile setting in Picture Window's Print dialog box set to *None*.

To print images from a color space other than sRGB, you need to create and use a custom printer profile. At this time, this can only be done using a third party color management package such as Monaco EZColor or Praxisoft WiziWYG.

When creating a custom profile and when subsequently printing images using the custom profile, it is important that you print any test pages with all color adjustments disabled. This is necessary because changes to the driver settings will invalidate the conditions under which the profile was created and will lead to inconsistent results. To disable color adjustments, first click the *Color Adjustment* radio button and then setting the Mode to *No Color Adjustment* (not *Automatic*) as illustrated below



This will ensure that any image data sent to the printer will be passed through the driver unmodified. When using this setting, you then specify the printer profile in the *Custom Printer Profile* and *Rendering Intent* controls in Picture Window's Print dialog box.

Scene Color vs. Photographic Color

It is important to make a distinction between *scene color* and the representation of that scene as captured in a photograph, either on film or as a print. Colors in the original scene arise from the intrinsic colors of the objects being photographed combined with the characteristics of the light with which they are illuminated. When a scene is photographed, its colors are then altered according to the characteristics of the color film being used and how it is processed. Finally, when a transparency or print is digitized, the characteristics of the scanner alter the colors once again.

Two different goals you might want to realize through color management are:

- *Accurate rendition of the color of the subject as it would appear under standard lighting conditions.*

This is called recovering scene color. Examples of this type of color matching goal might arise when photographing subjects such as:

A painting or other original art work.

An article of clothing or jewelry for inclusion in a mail order catalog.

Artifacts at an archaeological dig.

In these cases you may want to reproduce colors as accurately as possible as they would appear under standard viewing conditions such as daylight.

- *Accurate rendition of the colors in the film or print representation of the subject.*

This type of color matching considers the transparency or print as the original and assumes you want to simply reproduce the original photograph, preserving the character of the film image. This type of photographic color management is the most common and corresponds to the workflow described so far in this document.

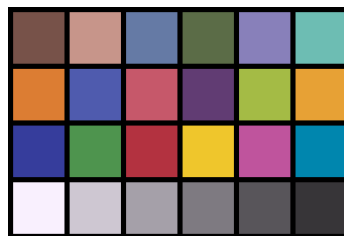
Recovering Scene Color Using ICC Profiles

When you profile a scanner, the reference colors to which you are calibrating are those of the original being scanned whether it is a piece of film or a print. To make the object being photographed the reference for a film scanner, you must photograph the IT8 or other calibration target under the same lighting conditions used to illuminate the object you are photographing and then use the photograph of the IT8 to create a custom scanner profile. This custom profile must then be applied to the image of the subject so as to correct it back to its original colors, thus canceling out

the effects of the color temperature of the illumination and the character of the film. This method can be used when it is important to accurately reproduce the color of the real world objects rather than simply reproducing the version captured on film.

Recovering Scene Color Using the Match Reference Transformation

A much more convenient though slightly less precise method of reproducing accurate scene color is to photograph a Macbeth ColorChecker along with the subject or, if this is impractical, to take a separate photograph on the same roll of film of a ColorChecker under the same lighting conditions as the subject.



Macbeth ColorChecker

The ColorChecker is a standard test target consisting of 18 color patches and 6 graduated gray patches. All but one of the colors lies inside the sRGB color gamut (the cyan patch is very slightly outside).

Having photographed and scanned the ColorChecker along with your subject, you can use Picture Window's *Match Reference* transformation to color correct the subject using the image of the ColorChecker as a reference. Since the brightness and color of each of the patches in the ColorChecker is manufactured to accurately known values, Picture Window can infer the correct brightness and color of the subject by comparing the observed colors of the ColorChecker to the known colors and computing the transformation necessary to restore the original brightness curve and colors to the entire image. The Macbeth ColorChecker comes in a very handy 2x3 inch version as well as the more common 9x13 inch size. For information on purchasing a ColorChecker, please see the section on Commercial Color Management Solutions at the end of this document.

In any case, accurately recovering the color of the subject is next to impossible unless it is illuminated uniformly by a single type of light. If the lighting is uneven, some parts of the image will be brighter than others and there will be no easy way to correct for this. Scenes with mixed illumination such as part fluorescent and part

incandescent or dappled sunlight create similar problems as different parts of the image require different corrections due to the varying brightness and spectral characteristics of the illumination.

When using a digital camera to capture the original images, you should either disable its automatic white balancing feature (if possible) or make sure you include the ColorChecker in the same image as the subject. If you photograph the subject and the ColorChecker in two different pictures and automatic white balance is turned on, you may not get a compatible pair of images. Similarly, it is important when scanning images for use with the Match Reference transformation that you scan the subject image and the reference image in exactly the same way. Any automatic corrections must be disabled.

Commercial Color Management Solutions

There are a several companies specializing in color calibration and custom profile creation hardware and software. As new products are announced frequently, you should check with the manufacturers for the latest information.

Types of Instruments

Some products come with or can be used with *colorimeters* or *spectrophotometers*. Colorimeters and spectrophotometers both measure device-independent color, but a colorimeter simply takes three measurements using colored filters while a spectrophotometer measures light in a series of narrow frequency bands making its measurements more accurate. There are three types of devices corresponding to the three kinds of color measurements that can be taken:

Self-Luminous—for reading monitors. These devices are usually equipped with suction cups so they can be attached to the face of a CRT. For self-luminous readings light emitted by the monitor (or other light source) is measured directly.

Reflective—for reading the color of prints or colored objects. For reflective readings the target is illuminated with a light source of accurately known characteristics and the color of the reflected light is measured.

Transmissive—for reading the color of film or other transparent or translucent media. For transmissive readings, the target is placed between the sensor and a calibrated light source and the color of the light passing through the target is measured.

In some cases, the same device can be configured with accessories to make two or even all three types of measurements. Most inexpensive instruments are manually operated, but for heavy production use, some devices can read film or paper strips automatically, and this can be a huge time saver.

Vendors

The following is a list of some of the leading suppliers of color management software and hardware for Windows at this time.

Monaco Systems

<http://www.monacosys.com>

(978) 749-9944

MonacoEZColor (\$299)

MonacoEZColor Bundle (\$499)

The basic EZColor is a software-only monitor, flatbed scanner, and printer calibration and profiling system. You create scanner and printer profiles by printing a special test page and then scanning it along with an IT8 reference target on your flatbed scanner.

The bundle includes a Sequel Imaging monitor colorimeter for more accurate monitor calibration. A test target for profiling transparency scanners is available for an additional \$40.

Praxisoft

<http://www.praxisoft.com>

(800) 557-7294

WiziWYG (\$79)

WiziWYG Plus (\$199)

WiziWYG Deluxe (\$599) -- available sometime in 2000

WiziWYG is a software-only calibration and profiling system for monitors, flatbed scanners, and printers. You create scanner and printer profiles by printing a special test page and then scanning it along with an IT8 reference target on your flatbed scanner.

WiziWYG Plus adds support for profiling transparency scanners; WiziWYG Deluxe includes a Sequel Imaging monitor colorimeter and will replace WiziWYG Plus when it becomes available. The Deluxe version does not include an instrument for measuring prints but it does support their use.

ColorBlind

<http://www.color.com>

(978) 749-9944

ColorBlind MatchBox (\$999)

The MatchBox calibration and profiling system works with but does not include monitor calibration hardware. However it does come bundled with a ColorSavvy ColorMouse which is a colorimeter for measuring printer output. MatchBox comes with ProveIt! which is a monitor calibration program that works with the Sequel Imaging monitor colorimeter as well as various other monitor measurement instruments. The Windows version of this package is quite sophisticated but is harder to use than EZColor or WiziWYG and still has a few kinks to be worked out. ColorBlind's parent company ITEC is experiencing financial problems so the long term viability of their products is under something of a cloud at this time. There have been no updates to the Windows versions of their software is quite a while and they are not entirely stable.

Color Vision
<http://www.colorcal.com>
(800) 554-8688

PhotoCal with MC7 Sensor (\$199 USB, \$299 Serial)
OptiCal with MC7 Sensor (\$399 USB or Serial)

PhotoCal is a monitor calibration and profiling system that comes with Color Vision's 7-channel monitor measuring instrument which they claim is more accurate than other low cost devices. OptiCal is a sophisticated package that gives you more information and control than most other programs and does an excellent job of monitor calibration. The MC7 7-color sensor is claimed to be more accurate than the more usual 3-color colorimeter that most other vendors use.

X-Rite
<http://www.xrite.com>
(616) 534-7663

X-Rite manufactures densitometers, colorimeters and spectrophotometers. The following models are the most useful for color calibration and profiling:

DTP41—a high quality spectrophotometer that automatically reads sheets of color patches. Models are available that can read film strips as well.

Digital Swatchbook—a low cost manually operated spectrophotometer for making reflective measurements.

Monitor Optimizer—a spectrophotometer for monitor calibration.

Avoid the **Colortron II** as it is very slow and not very accurate.

GretagMacbeth
<http://www.gretagmacbeth.com>
(914) 565-7660

GretagMacbeth manufactures a full line of color-related hardware and software.

The Munsell division of MacbethGretag produces the widely used *Macbeth ColorChecker* color charts. The ColorChecker comes in two versions:

Part #	Description
50111	Mini ColorChecker (2"x3")
50105	ColorChecker (9"x13")

The larger version is widely available from photo supply houses—the smaller one is much more convenient but is hard to find in stores. It is available directly from the GretagMacbeth, however. In spite of its diminutive size, the small one is actually a little more expensive than the large one.

GretagMacbeth also manufactures densitometers, colorimeters and spectrophotometers including the Spectrolino.

Spectrolino—a very high end spectrophotometer that can be used to measure self-luminous, reflective and transmissive targets. The Spectrolino can be adapted with their **SpectroScan** accessory to measure entire sheets of color patches automatically.

Ott-Lite
<http://www.ott-lite.com>
(800) 842-8848

Ott-Lite manufactures fluorescent desk and floor lamps with special True-Color bulbs whose color, according to my measurements, has a color temperature around 5500°K. If your monitor's white point is set to D65, prints viewed using these handy and relatively inexpensive lamps should match the screen quite nicely. Ott-Lites are available for around \$60 to \$70 from sup-

ply, sewing supply, and various other mail order supply houses, making this an attractive alternative to much bulkier and more expensive commercial viewing booths (see below).

GTI

<http://www.gtilite.com>

(914) 562-7066

GTI manufactures an extensive line of commercial viewing booths, light boxes, and other color corrected lighting. For critical viewing and comparison of prints and transparencies to a monitor, a controlled light source is enormously helpful if not essential. The better models let you adjust the brightness of the illumination, and this is very helpful when comparing prints or transparencies with a monitor as it is hard to compare two images when one is significantly darker than the other.

Horses

<http://www.horsesllc.com>

(212) 475-4712

Horses manufactures MatchLock plug-ins that let you create, edit and apply color profiles from within Photoshop. If you have a full versions of Adobe Photoshop (not the LE version) for either Windows or Macintosh, you can use MatchLock Profiler to create custom printer and scanner ICC color profiles. More advanced versions of their software let you edit profiles and perform certain previewing operations from within Photoshop.