Most all photographers who experienced the ‘film to digital’ transition have seen their photographic results improve significantly\(^1\). At the same time the photo industry has grown much larger in terms of products, software and services. Any doubt about these assertions will be put aside by a quick look at just the size of the current B&H Photo catalog!

Most all of us who experienced this transition have regarded our digital cameras as a ‘logical successor’ to their film predecessors. Accordingly, we’ve spent little or no time examining the fundamental differences between the two technologies. The object of this presentation is to take an ‘under the hood’ look at digital technology and the opportunities it creates for knowledgeable users to deliver further significant improvement in photographic results.

**INTRODUCTION**

I began making photographs back in the late 1960’s but photography became much more important when I became a certified SCUBA diver in 1985. In the years up to 2003, I was certainly aware that digital technology was ‘on the scene’ and that eliminating the need to carry and protect the large quantities of film I needed for my month-long trips to remote locations was very attractive. But I resisted making the switch because of my large investment in underwater cameras, housings, and related equipment. What changed my mind was seeing first-hand the digital advantages of removing the ‘36 image’ limitation which was fundamental to film\(^2\), and gaining the instant feedback of immediately viewing my current shot on the camera’s LCD screen. Like most film shooters making the digital transition, I had only the vaguest notion of Photoshop and ‘post processing optimization’ and my knowledge of the difference between film and digital technology was limited to knowing that the former was ‘analog (continuous)’ while the latter was ‘digital (or discrete)’\(^3\).

However there is one change from film that has been substantially underemphasized by just about everyone\(^4\). That change is the subject of this presentation. It goes by the acronym ETTR and is deceptively simple. To understand ETTR, I think its best to start with some basics.

**BASICS**

Figure 1 shows a film characteristic curve, something most film shooters probably can recall from the dim past. Ideally, most exposure took place in the ‘straight (black) line’ portion of the

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1. A few years ago I judged a ‘slide competition’ at CACCA. At that time the rules allowed for both conventional slides (from film) as well as ‘digital slides’ created from a digital file processed through a ‘film recorder’. It was pretty obvious which entries were which. For example all of the full frame birds in flight were ‘digital’; such an image would be essential impossible with film!
2. And an especially critical issue for underwater photographers since you cannot change film in that environment!
3. Furthermore, I could not foresee how many other improvements digital technology would bring to photo equipment (cameras, and lenses in particular), to related software, and to display alternatives (printing, slide shows, etc) in the succeeding years.
4. An exception to this under-emphasis is a recently published 64 page monograph written by Bob DiNatale and available in pdf format for $10 at: [http://onezone.photos/author/bobd/](http://onezone.photos/author/bobd/)
curve. And more importantly, the ‘stops’ in film photography were linearly distributed along the horizontal axis (red lines) of the curve. What this meant was that the negative (or positive with transparency film) has essentially equal detail in each of its stops as defined by the vertical lines. Film is a ‘linear system’; each increment of additional exposure produces an equal increase in detail, within the straight line portion of the exposure curve.

Digital systems behave very differently. Their ‘bit depth’ determines the amount of detail. Adding each additional bit doubles the total detail. A 1-bit system (Figure 2) has 2 levels of detail; think ‘black’ and ‘white’. A 2-bit system (Figure 3) has double the detail of the 1-bit system or 4 levels of detail (think black, white and 2 shades of gray). A 3-bit system (Figure 4) has double that of a 2-bit system or 8 levels of detail, and a 4-bit system (Figure 5) has double that of the 3-bit system or 16 levels of detail. In general, the levels of detail in a digital system is $2^n$, where $n$ is the number of bits in the system. As you can see from these numbers, the ‘last’ bit added is especially important since it contains fully half of the total detail in the system. For example, in the 4-bit system of Figure 5, half of the 16 levels are in that 4th bit!

In 2004 Bruce Fraser addressed the digital difference in an Adobe White Paper entitled ‘Raw Capture, Linear Gamma, and Exposure’\(^5\). At the time Bruce wrote his paper most all cameras’ RAW mode recorded 12-bits of data, which means they sorted incoming photons (of light) into $2^{12}$ or 4096 levels\(^6\). Since each bit doubled the data, half of the 4096 total levels are devoted to the brightest stop, half of the remaining 2048 or 1024 are devoted to the next stop, half of the remaining 1024 or 512 are devoted to the next stop, and so on. Figure 6 shows this distribution assuming a six stop sensor range; more stops and the number of levels in the darkest stop are even fewer. This so-called ‘Linear Distribution’ is

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\(^6\) When you convert a RAW image to JPG the 12-bits are converted to 8-bits ($2^8$ or 256 levels). The image you see on the camera’s LCD screen is an 8-bit JPG.
most certainly not linear at all in the way it disproportionately allocates levels ... the allocation is heavily skewed in favor of the lightest portions of an image. This also explains why digital noise is so much more evident in the shadow areas of an image. Noise is ubiquitous, meaning that it is present throughout the image, regardless of tone. However it is ‘proportionally’ much more evident in shadows (where there are few levels) than in highlights (where there are abundant levels).

In a digital image, detail is not equal in each of the stops. Rather it is overwhelmingly greater in the lighter stops, as you can see in Figure 6. Should you inadvertently underexpose by one digital stop, you’ve lost half of the detail available for the image! Since Fraser wrote his article, camera manufacturers have gone from 12-bits to 14-bits which seem like a small change until you do the math. As it turns out the 13-bits doubles the total levels from 4096 to 8192, then adding the 14th bit doubles the levels again to a whopping 16,384 levels (Figure 7). To put this another way, going from 12-bits to 14-bits has increased the available detail the newer cameras can capture four-fold!

The way in which to use your camera to better capture as much of the brightest stop data as possible is to expose-to-the-right or ETTR. Sounds simple enough; take a test shot and if the histogram is not all the way to the right, add some exposure and repeat until the histogram shows an ever-so-slight ‘blinky’ in a non-critical area. But we all know that nothing is ever as simple as it first seems! Applying that thinking simplistically, here’s what happened to me!

Figure 8 is an image I made in Fort DeSoto State Park just southwest of Tampa. The
bird ‘looks’ properly exposed and the histogram on the LCD of my digital camera indicated as much. However, when I checked the RAW file in Lightroom, I found that it was necessary to move the Exposure slider to the right by 1 2/3 stops before any ‘highlight clipping’ occurred. This meant that my RAW file had no data in the brightest stop, and almost no data in the next-to-brightest stop. Losing all the levels in those first stops meant that I’d missed 67% of the detail the camera (more properly used) could have supplied.

The reason for the difference between the ‘camera histogram’ and the ‘RAW histogram’ is due to the fact that the former is based on a JPG interpretation of the image. That JPG version is significantly influenced by camera settings, and is generally underexposed relative to the RAW histogram. My reliance on the ‘Standard Picture Style’ caused me to miss 75% of the image’s available digital data. I’ve since created a set of User Defined settings to produce minimum change from the RAW file.

Keep in mind that all of this discussion of detail and exposure does not mean that the image of Figure 8 is ‘bad’; but it sure means that it could have been better. It also means that a better digitally exposed image would have looked ‘thin’. The bird’s feathers would pretty much all have fallen very close to overexposure and therefore ‘lacked detail’. But the final result after adjustment in Lightroom or Photoshop would have been superior to what I was able to achieve with Figure 8 because I would have been able to show the viewer a greater range of contrast in the birds white feathers; pretty important for an all-white bird!

**OPTIMUM DIGITAL EXPOSURE IN THE STUDIO**

In his monograph titled ‘The Optimum Digital Exposure’, which was released as an eBook in 2014, Bob DiNatale describes a method for testing digital exposure in your camera. The method is to spot meter on a white card and then with constant aperture shoot a succession of images at one-third stop intervals of progressively longer shutter speed until the resultant image is severely overexposed. Figure 9 shows a graphical interpretation of ideal results of this test. The first exposure is at middle-gray or 128, 128, 128 in Photoshop. In Lightroom, this value is reported as R50, G50, B50, in other words 50% of the way to 100%.

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7 I made over 2000 bird exposures that week in the spring of 2014 and those that includes a white bird pretty much all fell into this category.
8 In Canon these settings are in the ‘Picture Style’ with several ‘Styles’ available, each controlled by Sharpness, Contrast, Saturation and Color Tone. In Nikon the settings are in termed ‘Picture Controls’ again with several ‘Options’, each controlled by Sharpening, Clarity, Contrast, Brightness, Saturation and Hue.
9 The Standard Picture Style settings for my Canon 5DSr are: 2, 4, 4, 0, 0, 0. My new User Defined Picture Style settings are: 0, 1, -3, -3, -3.
10 I shot this image with a Canon EOS 7D, which has a 14-bit sensor, so there’s a total of 16,384 level available. Missing all of the 14th bit means I ‘lost’ that bit’s 8,192 levels, missing 2/3 of the 13th level added another 2,795 levels, bringing the total to 10,987 or 67% of the total available.
sensor saturation (overexposure). As one increases exposure in one-third stops, the values increase in an almost straight line up to about 2-stops and 88%. But then the curve changes shape and it takes almost another 2-stops before one gets to 100%, or as DiNatale says ‘the top 2-stops of the camera exposure are compressed in the top 10% of your software brightness’. Figure 9 makes it clear that it’s easy to inadvertently underexpose an image by as much as a couple of stops as I did in the case of the white ibis at Fort DeSoto and consequently lost almost 75% of the scene’s detail.

OPTIMUM EXPOSURE IN THE FIELD

‘Optimum Exposure’ as DiNatale calls it will make the initial image look too bright as compared to the result ‘normal exposure’ would produce, but that can easily be corrected in image-optimization software. Having made the case for ‘optimum exposure’ the next issue is how to achieve it in the field. The ‘field problem’ is this: we’re trying to create an ‘optimum RAW exposure’ in the field but we know that the exposure we see on the camera’s LCD (a JPG interpretation) is not what we’re going to see when we open the RAW file in Lightroom (or Adobe Camera Raw). The conservative Picture Style settings I chose earlier make the difference less but not good enough!

DiNatale recommends either of two methods for addressing this issue: one is to use a handheld spot meter to meter the brightest object in a scene and adjust exposure accordingly; the other is to use the camera’s AEB feature to automatically bracket at +2/3, +1/3, and +2 stops. The latter method works well with situations where one is using a tripod, but not at all for shooting moving subject such as birds in flight. The former method means purchasing a spot meter which currently lists at B&H for $600.

I think it’s possible to accomplish the objective of ‘optimal exposure’ using the camera’s spot meter. **Note: in all of this next group of images, you are looking at screen captures from Lightroom; in other words, you’re looking at screen captures of the RAW file.** In Figure 11 I started out by spot metering on the blue sky in the top right corner of the image. I shot a series of exposures, decreasing the shutter speed in 1/3-stop intervals. The +2EV image was right on the edge of overexposure. Figure 12 is another example shot at the St. James Farm Forest Preserve; once again the +2EV image was right on the edge of

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12 Film shooters would use term ‘thin’ to describe a comparable negative.
overexposure. Figure 12 is still another shot, in which I found that the ‘optimal exposure’
was +2EV when the ‘normal exposure’ was based on a camera spot metering of the blue
sky. In this case there’s large areas of the RAW file warning of exposure but the highest
values I was able to find were R^{99.2}G^{99.4}B^{99.9}.

Figure 11 shows some trees at Herrick Lake Forest Preserve. The image on the left was spot metered in the sky and
shot in shutter priority at 0EV. The image on the right is at +2EV. In the screen capture from Lightroom you can see
a few areas (in red) warning of overexposure. In fact the brightest of these in Lightroom measured R^{98.8}G^{99.1}B^{99.9}
and so was not quite overexposed.

Figure 12 (above) shows a snow covered oak tree at St. James Farm Forest Preserve. The im-

age on the left was spot metered in the sky and shot in shutter priority at 0EV. The image on the
right is at +2EV. In the screen capture from Lightroom you can see a few areas (in red) warn-

ing of overexposure. In fact the brightest of these in Lightroom measured R^{99.9}G^{99.9}B^{99.9}.

Figure 13 (above) shows a line of trees at Cantigny Golf Course. The image on the left was spot
metered in the sky and shot in shutter priority at 0EV. The image on the right is at +2EV.
Because the camera’s JPG interpretation includes some ‘optimization’ input by the camera Picture Style software, there is definitely a difference between the above and what I saw on the LCD screen. Most all of my tests show that when the JPG image shows slight overexposure warning, one needs to add $+\frac{2}{3}$ EV to produce a RAW image version which is just on the verge of overexposure.

**IN THE FIELD AT TAHQUAMENON FALLS**

In the fall of 2015, I took ETTR to the field in Michigan’s Upper Peninsula and discovered that the technique produced improved detail and an additional ‘surprise’ benefit!

**Figure 14** and **Figure 15** are examples of ‘normal’ and ‘optimum’ exposure respectively. Both were shot from a single tripod setup with an f/11 aperture setting. **Figure 14** was matrix metered and shot at 1/320 second; **Figure 15** used identical metering but was shot at 1/50 second.

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**Figure 14** (left) and **Figure 15** (right) are two shots of fall color at Upper Tahquamenon Falls in Michigan’s Upper Peninsula. **Figure 14** is a ‘normal’ shot which used matrix metering, an f/11 aperture, ISO 400 and a 1/320 shutter speed. **Figure 15** (right) is an ‘optimal’ exposure made with the same settings except a longer (1/50) shutter speed.

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13 There’s good reason for the ‘optimization’ added by the Picture Style software. Many professional photographers work under extreme time constraints and need to submit their results almost immediately with no opportunity to optimize in Lightroom or Photoshop. This is especially the case for sports and wedding photographers. These professionals know the RAW file will be flat and rely upon their Picture Style settings to produce a result satisfactory to the end result.
Figure 16 (left) and Figure 17 (right) are Figure 14 and Figure 15 respectively, optimized in Lightroom’s Basic Panel, and with the default Color Noise setting reduced to ‘0’ in both cases.

Figure 18 shows an enlargement of the left edge of the image just above the waterfall; the left version is from the ‘normal exposure’ while the right version is from the ‘optimal exposure’.
1/50 second (+2\( \frac{2}{3} \) stops). The sky is the brightest feature in both. Before any adjustment the brightest part of the sky in Figure 14 measured \( R^{97.3}, C^{97.3}, B^{96.8} \). In Figure 15, the same spot measured \( R^{99.9}, G^{99.9}, B^{100} \). Figure 14 looks a little underexposed and if you compare the sky highlights to the chart in Figure 9 it looks like it’s about 3 stops underexposed from ‘optimum’. Figure 15 looks severely overexposed, but it’s very close to ‘optimum’ according to Figure 9. The results so far show no apparent advantage for the ‘optimum exposure’ process.

In Figure 16 and Figure 17 both images were adjusted in Lightroom’s Basic Panel for a full tonal range and the default Color Noise Reduction\(^1\) set to ‘0’. These results are a lot better than Figure 14 and Figure 15; in particular the colors of Figure 15 are richer. The ‘surprise’ is still to come, but you may be able to guess where it will show up. The ‘normal’ image has plenty of detail in its highlights; it’s only when you get to the darker stops where the advantage of the ‘optimum’ image will become apparent.

\[ \text{Figure 18 and Figure 19 make clear the advantage. Figure 18 is an enlargement of a segment of the left edge of the scene just above the waterfall; the left image is the ‘normal’ and the right image is the ‘optimal’. The amount of color noise in the left hand image is significant; there is no color noise in the right hand image. The right hand image appears sharper and shows a broader range of tones. These results are to be expected because the added } 2\( \frac{2}{3} \) \text{ stops of exposure mean that the detail available in the right hand image is roughly 6 times greater than on the left, and this difference will be especially significant in} \]

\[ \text{Figure 19 is a another enlargement of the image, this time of the orange tree on the right side of the image, once again just above the waterfall. The ‘normal’ exposure is on the left and the ‘optimal’ to the right.} \]

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\[ \text{14 ‘Noise’ is typically divided into ‘color noise’ and ‘luminosity’ noise. Color noise looks like confetti (typically magenta and cyan) scattered throughout the darkest areas; luminosity noise looks like fine grains of sand once again scattered throughout the darker areas of the image. IMHO the term ‘noise reduction’ is somewhat misleading. What noise reduction software typically does is to apply a slight blur which when applied properly ‘mashes’ the confetti and/or sand to make it less visible. Keep in mind that blurring is the enemy of sharpening.} \]
shadow areas of the image. Figure 19 is an enlargement of an area on the right edge of the image centered on the orange tree just above the waterfall. Again, the version on the left is the ‘normal’ while the version on the right is the ‘optimal’. You can see color noise in the sand just below the orange tree in the ‘normal’ but no color noise in the ‘optimal’. Looking at the orange tree itself as well as the sand beneath it, you can see increased sharpness as well as a greater range of tones (more contrast).

I think these comparisons make a clear case for the ‘optimal exposure’ principle. In addition to what you can see in Figure 16 and Figure 17, the ‘optimal’ version is less sensitive to processing artifacts which are significantly more likely to emerge in the ‘normal’ image (Figure 16) because there is simply less data to work with than in the ‘overexposed’ image (Figure 17).

IN THE FIELD AT WHITE SANDS

The week after Thanksgiving, 2015, I took the opportunity to apply these ideas about ETTR at White Sands and Bosque del Apache, two great photo locations in New Mexico.

White Sands National Monument is located about 14 miles west of Alamogordo. The park includes over 275 square miles of wave-like dunes of very white gypsum sand. The dune sand formations make interesting photo subjects best framed against the San Andres Mountains which are east of the park. There are areas of foliage in White Sands, principally Soaptree Yucca (Yucca elata) and Rabbitbrush (Ericameria nauseosa) which can be interesting features in dune detail photos. I did all my shooting at White Sands from a tripod using a Canon EF 24-70mm f/2.8L II lens on a Canon 5DS R body. The camera was setup with matrix metering in shutter priority, generally with an f/11 aperture. For each composition I shot a series of images in one-stop increments from 3-stops under-exposed to as much as 5-stops over-exposed. As it turned out, shooting the 7-9 image sequences, created significant opportunities for illustrating the benefits of ETTR.

Figure 20 is the dune composition using ‘normal exposure’. Figure 21 is a 4:1 enlargement of the top-left corner selected so as to include both portions of the mountains and the dunes. Notwithstanding the limitations of laser printing, you can see the pink and turquoise confetti which is Color Noise. There is also plenty of Luminance Noise which looks like fine sand, but it’s masked by the Color Noise.

15 This is my typical HDR procedure; however the increased dynamic range of the Canon 5DS R along with the limited dynamic range of these scenics made the HDR unnecessary.
Figure 20 is a dune composition with the San Andreas Mountains in the background; this is the normal exposure; it gives you a good perspective of the overall scene. Figure 21 is a 4:1 enlargement of an area at the top-left corner of Figure 20 with the Color Noise set to ‘0’. You can clearly see the noise (pink and blue confetti) on both the mountain and especially in the sand. Note: the Lightroom default setting for Color Noise is ‘25’ which setting pretty much eliminates the problem you see in Figure 21, however noise reduction is actually ‘constructive blurring’ which is quite the opposite of sharpening!!

As an alternative, consider the same scene photographed at 4-stops over-exposed; an ‘optimum exposure’ as we’ve defined in the previous examples. Figure 22 is what you see on the camera’s LCD. As I pointed out earlier, what you see on the LCD screen appears to be ‘more over-exposed’ than what you’ll see when you open the RAW file. Figure 23 is the actual RAW file in Lightroom before any Development adjustments. In Figure 24, the only adjustment was to set Lightroom’s Exposure slider to -4-stops. Figure 25 shows the same enlargement as Figure 21; but there is none of the Color Noise you see in Figure 21.

Figure 22 through Figure 25 show the same composition 4-stops overexposed. Figure 22 (above, left) is what you see on the camera’s LCD screen. Figure 23 (above, right) is the actual RAW file in Lightroom before any Development adjustments. In Figure 24 (below, left), the only adjustment was to set Lightroom’s Exposure slider to -4-stops. Figure 25 (below, right) shows the same enlargement as Figure 21; but there is none of the Color Noise you see in Figure 21.

16 ‘Normal exposure’ is the exposure that the camera would choose in shutter priority, aperture priority, or program mode with no exposure compensation.
17 What you see on the camera’s LCD screen is the camera’s JPG ‘interpretation’ of the RAW file, which makes the JPG look more overexposed (more red) than is the case for the RAW file. The interpretation is influenced by the ‘picture style’ settings, especially the settings for Contrast and Sharpening. In my tests I find this effect is equivalent to about 2/3-stop.
again with Color Noise set to ‘0’. What happened to the Color Noise? It’s all about ETTR. The difference between the exposure in Figure 20 and Figure 24 is 4-stops; each stop doubles the number of levels of information, so Figure 24 has 16 times more information than does Figure 20. Another way of saying this is that the signal (information) to noise ratio in Figure 25 is 16 times greater than in Figure 21. In fact the noise is still there in Figure 25 but it’s just been ‘drowned out’ by the much increased signal (information) strength.

IN THE FIELD AT BOSQUE DEL APACHE

The other location I visited in New Mexico was the Bosque del Apache NWR which is the migratory winter destination for large numbers of Sandhill Cranes as well as both Snow and Blue Geese. The refuge is located about 15 miles south of Socorro, roughly 100 miles north of Alamogordo. The cranes overnight in either of two ponds (about 200 yds. long by 50 yds. wide) conveniently located on the west side of the road going into the refuge. The ponds are shallow, surrounded by an earthen berm. Parking is between the access road and the berm. Figure 26 shows a line of photographers standing on the berm overlooking one of the ponds; a lot of folks and a whole lot of glass!

Photographing these birds is very, very different from the work I did at White Sands. Here I used a Canon 7D Mark II body and either a Canon EF 500mm f/4L or Canon EF 100-400 f/4.5-5.6 IS II lens both with a 1.4 Teleextender. The effective focal lengths for the lens combinations (including the 1.6 crop factor of the camera) were 224-896 mm for the 100-400 lens

Figure 26 shows a line of photographers alongside one of the crane ponds. This is a PM shot so the photographers are looking towards the refuge for cranes en route back to the overnight in the ponds.

Figure 27 is a couple of my favorite Sandhill crane shots from Bosque del Apache.
and 1120 mm for the 500 mm lens. The camera setup is quite different too. At Bosque, I had the camera setup for spot metering (not matrix), shot mostly in Manual exposure and used focus tracking (single center or center plus 4 adjacent points). I shot in burst mode (up to 10 frames/second) and used ‘back button focus’ with both the ‘*’ and ‘AF-ON’ buttons set for ‘AF start’.

Shooting birds-in-flight at Bosque is very different from creating interesting compositions at White Sands. At Bosque the birds control the action; at times incredibly hectic, at other times ‘dead’. Both environments require both practice and patience. Both invariably produce a ‘learning experience’. At Bosque I learned that trying to manage exposure as the incoming birds moved from a brightly lit background (sky) to a lower light environment (ground) was next to impossible in either conventional Manual or conventional Shutter Priority mode. Consequently I was not successful implementing ETTR with the birds at Bosque.

In retrospect, the better alternative would have been ‘Auto ISO’. In that mode, I could have set the chosen the fast shutter speed needed to stop these birds (preferably 1/1000 sec.) as well as fixed an appropriate aperture (f/8) sufficient to get all of the bird and its 8ft. wingspan in focus. ‘Auto ISO’ lets you set both shutter speed and aperture as necessary, and then automatically adjusts the ISO as the light changes. This pretty much eliminates any need to change exposure during a shoot. Needless to say I’ve put this at the top of my ‘to do’ list for my next Bosque or L&D#14 trip. One might expect that in ‘Auto ISO’ it would not be possible to set the camera to shoot at a specific aperture (say f/8), a specific shutter speed (say 1/1000 sec.) and to at the same time automatically apply positive exposure compensation (say +2-stops). However, Canon has made this possible in newer model prosumer cameras. Here’s how I set it in the 7D Mark II:

1. Go to the ‘Custom Controls’ screen at the bottom of Custom Function tab 3 (red camera icon just to the left of the green ‘My Menu’ button at the right end of the Menus display (see page 445 of the camera Instruction Manual). Press ‘Set’.
2. Scroll down to the Area Selection Lever (pg. 56), press ‘Set’ and then scroll over to the Exposure Compensation icon and choose it by again pressing ‘Set’.
3. You can now dial in the +2 stops of exposure compensation tilting the Area Selection Lever to the right and then dialing in the desired exposure compensation.

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18 Morning temperatures at Bosque were in the mid-teens and gloves were essential. With both buttons enabled for focus, pressing either button ‘got the job done’ and reliable with gloves on.
19 You can download the complete camera Instruction Manual (which is no longer included with the camera) from the Canon website.